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# Filmwise Condensation of Steam on Horizontal Wire-Wrapped Smooth and Roped Titanium Tubes

by

Thomas Joseph O'Keefe
Lieutenant, United States Navy
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Results obtained for the wire-wrapped smooth titanium tubes showed a maximum enhancement of 30% as compared to a smooth titanium tube. This was for a tube using a 0.5 mm wire diameter (P/D = 7.92), corresponding to a fraction of the tube covered by the wire of 12%. The LPD KORODENSE titanium tube showed an enhancement of 20% compared to a smooth titanium tube for both atmospheric and vacuum pressures. The addition of wrapping a wire in the grooves of the LPD tube showed no further significant enhancement for the three wire dianmeters tested.


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## ABSTRACT

Filmwise condensation heat-transfer measurements were performed on horizontal smooth and roped titanium tubes using steam. The roped tubes were a commercially available tube (KORODENSE) with a nominal pitch of 7 mm. To further enhance the outside heat-transfer coefficient of both the smooth and roped tubes a wire was tightly wrapped around the tubes. To see the effect that the wire diameter and wire pitch had on the enhancement, 3 different wire diameters were used (nominal diameters of 0.5, 1.0, 1.6 mm) giving a range of wire pitch to wire diameter ratio of between 2 and 9. Tests were conducted under vacuum and atmospheric pressure conditions. The data reduction technique used the modified Wilson plot.

Results obtained for the wire-wrapped smooth titanium tubes showed a maximum enhancement of 30% as compared to a smooth titanium tube. This was for a tube using a 0.5 mm wire diameter ($P/D_w$ = 7.92), corresponding to a fraction of the tube covered by the wire of 12%. The LPD KORODENSE titanium tube showed an enhancement of 20% as compared to a smooth titanium tube for both atmospheric and vacuum pressures. The addition of wrapping a wire in the grooves of the LPD tube showed no further significant enhancement for the three wire diameters tested.

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## NOMENCLATURE

| | |
|---|---|
| a | as defined in equation (4.23) |
| $A_i$ | effective inside surface area, $m^2$ |
| $A_o$ | effective outside surface area, $m_2$ |
| b | as defined in equation (4.22) |
| c | as define in equation (4.15) |
| $C_i$ | leading coefficient for the inside heat transfer correlation used |
| $C_p$ | specific heat at a constant pressure, J/kgK |
| d | as defined in equation (4.15) |
| $D_i$ | tube inside diameter, m |
| $D_o$ | tube outside diameter, m |
| $E_T$ | enhancement ratio based on $\Delta T$ |
| F | fraction of the tube covered by wire |
| $F^*$ | as defined in equation (2.3) |
| g | gravitational constant, 9.81 m/s |
| $h_{fg}$ | specific enthalpy of vaporization, J/kg |
| $h_i$ | inside heat transfer coefficient, $W/m^2K$ |
| $h_o$ | outside heat transfer coefficient, $W/m^2K$ |
| $k_c$ | thermal conductivity of the coolant film, W/mK |
| $k_f$ | thermal conductivity of the condensate film, W/mK |
| $k_m$ | thermal conductivity of the tube material, W/mK |
| $K_1$ | as defined in equation (4.16) |
| $K_2$ | as defined in equation (4.16) |

$L$ active length of tube exposed to steam, m

$L_1$ length of inlet portion of tube, m

$L_2$ length of outlet portion of tube, m

LMTD log mean temperature difference, K

$\dot{m}$ mass flow rate of the coolant, kg/s

Nu Nusselt number

$P_{sat}$ saturation pressure, Pa

Pr Prandtl number

$Pr_w$ Prandtl number at the wall temperature

Q heat transfer rate, W

q heat flux, $W/m^2$

Re Reynolds number

$Re_f$ Reynolds number for the condensate film

$Re_{2\theta}$ two phase Reynolds number

$R_i$ inside thermal resistance, $m^2K/W$

$R_o$ outside thermal resistance, $m^2K/W$

$R_{total}$ total thermal resistance, $m^2K/W$

$R_w$ wall thermal resistance, $m^2K/W$

$T_{cf}$ temperature difference across the condensate film, K

$\Delta T_f$ temperature difference across the film, K

$T_{sat}$ vapor saturation temperature, K

$T_1$ cooling water inlet temperature, K

$T_2$ cooling water outlet temperature, K

$U_o$ overall heat transfer coefficient, $W/m^2K$

$U_\infty$ vapor velocity, m/s

$V_w$ velocity of the coolant, m/s

| | |
|---|---|
| X | as defined in equation (4.19) |
| Y | as defined in equation (4.18) |
| Z | as defined in equation (4.12) |

Greek Symbols

| | |
|---|---|
| $\alpha$ | dimensionless coefficient |
| $\epsilon$ | as defined in equation (4.16) |
| $\mu_c$ | dynamic viscosity of the coolant, kg/m s |
| $\mu_f$ | dynamic viscosity of the condensate film, kg/m s |
| $\mu_w$ | dynamic viscosity of the condensate at the wall, kg/ms |
| $\rho_f$ | density of the condensate film, kg/m$^3$ |
| $\rho_v$ | density of the vapor, kg/m$^3$ |
| $\eta$ | surface efficiency |
| $\Omega$ | as defined in equation (4.13) |

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# I. INTRODUCTION

## A. BACKGROUND

Since the Cold War has ended, the money allocated for new weapon platforms in the Navy has been greatly reduced. There is therefore an increased emphasis on making ships as cost efficient as possible. Technology has progressed to the point where the heat removal requirements of modern weapons systems have increased. Future classes of attack submarines are expected to be smaller in size and just as capable as the existing 688 class. This will require the main and auxiliary propulsion systems to be designed for maximum power with the smallest, lightest, and most cost efficient components. One method to reduce the main propulsion system size and weight is to use enhanced tubing in the main condenser. In addition, submarine and surface ship refrigeration systems can have larger capacities, and maintain the same approximate size and weight if enhanced tubing is used in the refrigeration condenser. The Naval Postgraduate School, with support from the David Taylor Research Center, has been conducting research on various types of condenser tubing with the object of designing smaller, lighter, and more efficient condensers.

The DDG-51 class of destroyers was originally designed to have enhanced titanium tubes used for the refrigeration

condenser to give significant weight reduction to the refrigeration plant. In submarines, the use of enhanced titanium tubes in the main and auxiliary condensers would lead to a major reduction in weight of the steam propulsion plant. Titanium has the advantage over copper-nickel, which is presently used in condensers, of a higher strength to weight ratio, as well as excellent corrosion and erosion resistance. This allows for thinner tube walls and higher coolant flow rates to be used, so the same overall amount of heat can be transferred [Ref. 1]. The improved performance of enhanced tubes allows the same amount of power to be produced at a lower turbine backpressure, allowing for the design of smaller, more efficient propulsion plants. Alternatively, a larger power output can be achieved at the same backpressure for a plant of the same size. Some of the disadvantages of titanium are that it has a much smaller thermal conductivity and it is very expensive compared to copper-nickel.

## B. CONDENSATION

Condensation occurs when a vapor is cooled below its saturation temperature, or when a vapor/gas mixture is cooled below its dew point. Condensation also occurs when a vapor comes into contact with a subcooled liquid. This is known as direct contact condensation. The most common type of condensation involved with heat exchangers is surface condensation. This occurs when the vapor contacts a surface

that is maintained below the saturation temperature of the vapor. Two types of surface condensation can take place. The first is filmwise condensation, so called because the condensate "wets" the surface with a continuous film. The second is dropwise condensation, so called because the condensate does not "wet" the surface, but instead forms distinct droplets of various sizes. Microscopic droplets coalesce to form large drops, which are then removed from the surface by gravity and/or vapor shear forces. Dropwise condensation results in much higher heat transfer coefficients (typically by an order of magnitude) than with filmwise condensation due to the fact that a certain portion of the cooled metal surface is exposed to the vapor. However, dropwise condensation is difficult to maintain over the life of a typical condenser. Many attempts have been made to promote dropwise condensation by using special surface coatings, but these tend to get 'washed' off in the little long term, reverting back to filmwise condensation. Therefore, condensers are normally designed to operate assuming filmwise condensation takes place, Thus providing for a conservative design [Ref. 2].

The heat transfer rate across a condenser tube is controlled by the tube wall, fouling, coolant side, and vapor side thermal resistances. For most laboratory experimental work, the tubes are thoroughly cleaned before testing, so the fouling thermal resistance is negligible. The other thermal

resistances vary depending on the condensing and coolant fluids used, tube geometry and material, and the flow conditions of the coolant and vapor. During condensation of steam, the coolant side thermal resistance is usually the dominant controlling resistance.

Methods of lowering the coolant side resistance include the use of inserts and roped tubes. However, any increase in heat transfer is offset by an increase in the pressure drop along the tube. Although inserts provide the best enhancement, the large pressure drop involved generally restricts their use to laminar flows and other specialist applications. Roped tubes, which tend to incur a much lower pressure drop, have been used successfully in a large scale condenser at the Gallatin Unit 1 300-MW power plant for the Tennessee Valley Authority. Low pressure drop (LPD) KORODENSE 90-10 Cu-Ni tubes were used to retube the condenser in August 1980 (LPD KORODENSE is a particular type of roped tube made by the Wolverine Tube Co.). Although it cost about $65,000 more to retube using the roped tubes, a projected savings of $908,000 is expected over the remaining life of the plant based on actual performance [Ref. 3]. The wall resistance is controlled by the type of material used and the thickness of the tube wall.

The vapor side thermal resistance is lowered essentially by thinning the condensate film. One way of thinning the condensate film can be achieved by changing the geometry of

the outside surface of the tube to utilize the surface tension effects of the fluid. Thinning the condensate film can significantly increase the heat transfer, especially for fluids like water where the surface tension is high. The use of fins, wire-wrap, and roped tubes have all been used to lower the vapor side resistance by causing an uneven pressure distribution through the condensate film on the surface of the tube.

## C. CONDENSATION RESEARCH AT THE NAVAL POSTGRADUATE SCHOOL

The Naval Postgraduate School (NPS) has been conducting condensation research on enhanced tubes since 1982. Van Petten [Ref. 4] provides a summary of the research efforts on single horizontal tube condensation at NPS from 1982 to 1988. In particular, the research has looked at many aspects of enhancing tubes with low integral fins. Previous researchers have varied the fin spacing, fin shape, fin material, and tube diameter to determine how the performance of the tube is affected. Work has been done on single tubes and tube bundles at various pressures. Several different types of working fluids have also been used: steam, R-113, and ethylene glycol. All of this has been done to determine if the performance of an enhanced tube can be predicted, and under what condition the maximum enhancement will be realized.

Previously, the modified Wilson plot technique has been used to find the outside heat-transfer coefficient. However,

without an accurate inside heat transfer correlation, past researchers have had trouble reducing their data to provide an accurate value of the outside heat-transfer coefficient. Swensen [Ref. 5] used an instrumented tube to find the values of the tube wall temperatures. With a mean wall temperature of the tube, the inside and outside heat-transfer coefficients could be calculated directly. He then developed several inside heat transfer correlations using his data, based on the form of the Sieder-Tate [Ref. 6] correlation. His research noted that the outside heat transfer correlations were very sensitive to the Reynolds number exponent.

### 1. Condensation Research Using Roped and Wire-Wrapped Tubes

Most of the single tube condensation research done previously at NPS has involved the use of smooth and low integral fin copper tubes. Only a few researchers at NPS have studied the effects of wire-wrapping smooth tubes in a condensation application. The first was Kanakis [Ref. 7] in 1983. He tested titanium smooth and roped tubes, both with and without wire wrapping, while condensing steam in a vertical in-line tube bundle; up to 30 tubes were simulated by using inundation tubes. Brower [Ref. 8] used the same apparatus as Kanakis to try and determined the effects of wire diameter and pitch on the steam side heat transfer coefficient and to compare the effect of condensate inundation on smooth

and wire-wrapped tubes. Kanakis and Brower showed that the wire-wrapped tubes were not significantly affected by inundation (i.e. the wire provided better drainage down the bundle) in a steam condenser bundle. In a different apparatus, Mitrou [Ref. 9] conducted research on single tubes, both finned and wire-wrapped. He studied the relationship between the wire pitch and wire diameter for several wire-wrapped smooth copper tubes. Mitrou's results showed that the enhancement of a wire-wrapped tube compared to a smooth tube could be as much as 80% for the same temperature drop across the condensate film. The largest enhancements corresponded to a $P/D_w$ ratio of between 5 and 7.

## D. OBJECTIVES

The main objectives of this thesis were:

1. To find an accurate inside heat-transfer correlation, which is not sensitive to the Reynolds number exponent, for use in the data reduction technique.
2. To manufacture and collect condensation data on a series of titanium wire-wrapped smooth and roped tubes.
3. To check the repeatability of results of past researchers on the enhancement in the outside heat transfer coefficient due to wire-wrapping a copper tube.
4. To determine any effect of wire pitch and wire diameter on the enhancement in the outside heat transfer coefficient as compared to a smooth tube.

## II. LITERATURE SURVEY

### A. INTRODUCTION

When filmwise condensation occurs on a smooth horizontal tube, a thin condensate film forms around the tube. This condensate film provides a resistance to the heat transfer across the tube, so if the thickness of the film can be reduced, then the heat transfer rate will increase. To reduce the thickness of the film, several different methods have been used including low integral fins, wire-wrapped, and roped tubes. In the past, it was thought that enhancing a tube in this way for steam condensation would be impractical because the high surface tension would cause condensate to be retained between the surface enhancement on the tube, degrading performance.

The Naval Postgraduate School has conducted extensive research in enhancing the heat transfer performance of condenser tubes. The direction of the experimental research recently has been to find the optimum tube for condensation using the various enhancement methods.

### B. FILM CONDENSATION OF STEAM ON A SMOOTH TUBE

In 1916, Nusselt [Ref. 10] showed that for a quiescent vapor condensing on a horizontal tube, the thickness of the condensate film varied around the tube. This variation led to

a variation in the local heat transfer coefficient, being a maximum at the top of the tube where the film is the thinnest. Nusselt's theoretical result for the mean heat transfer coefficient of a pure saturated vapor on a horizontal cylinder was:

$$h_o = 0.728\left[\frac{k_f^3 \rho_f(\rho_f-\rho_v) g h_{fg}}{\mu_f D_o \Delta T_f}\right]^{1/4} \tag{2.1}$$

Nusselt's equation has been verified experimentally for a stationary vapor surrounding the tube. However, in most steam surface condensers, the vapor is moving with some velocity. The velocity of the vapor affects the thickness of the condensate film due to the drag imparted on it by the vapor. Shekriladze and Gomelauri (1966) [Ref. 11] took this surface shear into account and derived the following theoretical equation for the mean Nusselt number (dimensionless mean heat transfer coefficient):

$$\frac{Nu}{Re_{2\theta}^{1/2}} = 0.64(1+(1+1.69F^*)^{1/2})^{1/2} \tag{2.2}$$

where:

$$F^* = \frac{Pr}{Fr\,Ph} = \frac{g D_o \mu_f h_{fg}}{U_\infty^2 k_f \Delta T_f} \tag{2.3}$$

$$Re_{2\theta} = \frac{\rho_f U_\infty D_o}{\mu_f} = two\ phase\ Reynolds\ number$$

$F^*$ is a dimensionless parameter which relates the gravity force to the shear force. At high values of $F^*$, where gravitational forces dominate, equation (2.2) reduces to the Nusselt equation shown in equation (2.1). A low values of $F^*$, equation (2.2) predicts significantly higher values of $h_o$ than equation (2.1) due to the action of the vapor shear forces thinning the condensate film.

Fujii et al [Ref. 12], in 1979, formed an empirical correlation for the vapor side Nusselt number from forced convection steam condensation data:

$$\frac{Nu}{Re_{2\theta}^{1/2}} = 0.96\,F^{*\,1/5} \tag{2.4}$$

Again, at high values of $F^*$, equation (2.4) gives the same result as equation (2.1).

In a situation where surface shear forces are significant for steam condensation, equation (2.4) seems to be the most accurate. The reader is referred to Rose [Ref. 13] for further reading on the topic of filmwise condensation on a smooth horizontal cylinder.

## C. FILM CONDENSATION ON WIRE WRAPPED TUBES

The technique of wrapping a wire around a smooth tube to enhance performance was first introduced by Thomas [Ref. 14] in 1967 for vertical tubes. He judged that the wire, creates a low pressure region at the base of the wire due to the small

radius of curvature. This low pressure region draws in condensate from between the wires (where the pressure is greater), thinning the condensate film and improving the outside heat transfer coefficient.

The same explanation can be used to explain why enhancement occurs for a horizontal wire-wrapped horizontal tube. Figure 1 is an idealized profile of a wire wrapped tube. The low pressure region forms at the base of the wire with the higher pressure region forms between the wires. The amount of heat transferred through the wire is usually negligible compared to the rest of the surface. This is not only because of the high thermal contact resistance between the tube and the wire but also because the thicker condensate layer that is formed at the base of the wire tends to inhibit heat transfer in this region.

**1. Summary of Wire-Wrap Tube Research**

Previous researchers have found that wire-wrapped smooth tubes can lead to significant enhancement over plain smooth tubes. Sethumadhavan and Rao [Ref. 15] used single wire-wrapped horizontal tubes in a steam condenser with negligible vapor shear and showed that the tubes had an outside heat transfer coefficient enhancement of between 10% and 45% over plain smooth tubes; unfortunately, the material of the tube was not specified. They used three different wire diameters, 0.71 mm, 1.5 mm, and 3.0 mm. The maximum

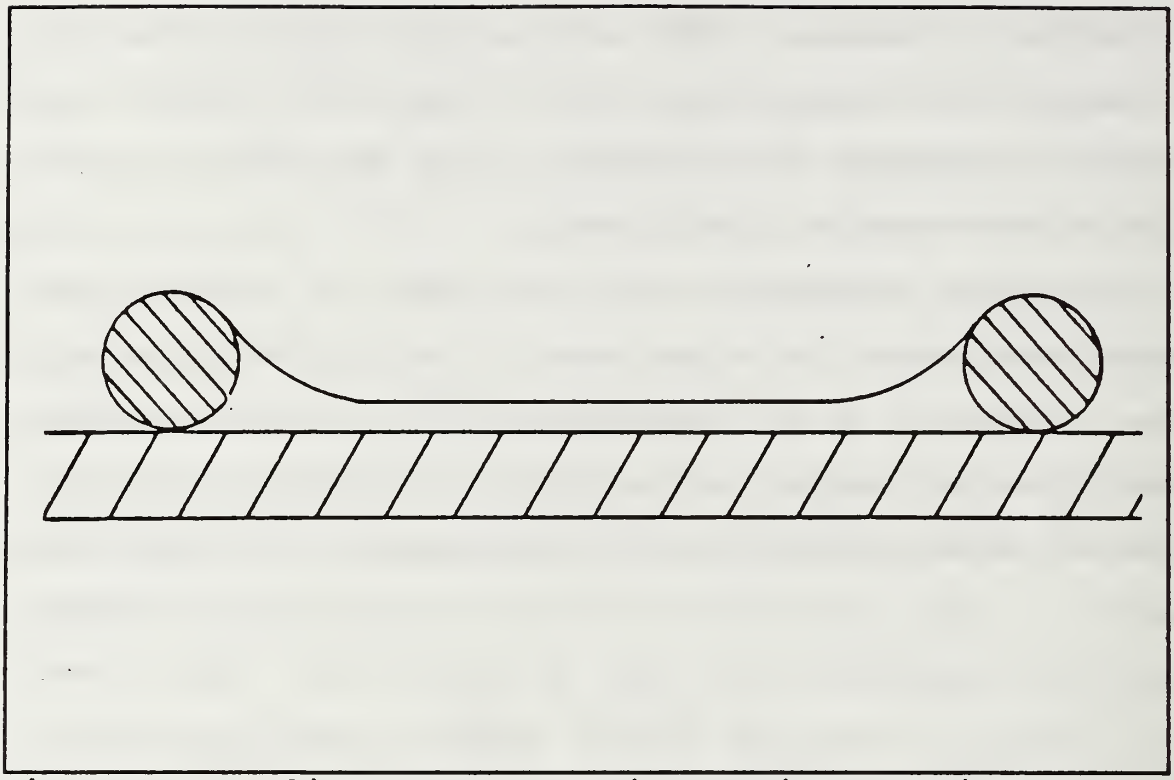

Figure 1. Idealized Condensate Film Profile on a Wire-Wrapped Tube

enhancement of 45% was obtained for the 3.0 mm wire at a pitch of 15 mm, giving a $P/D_w = 5$. The fractional coverage by the wire of the tube, F, in this case corresponded to 21%. They were trying to determine if there was a relationship between either F or $P/D_w$ and the heat transfer enhancement such that the performance of wire-wrapped smooth tubes could be predicted.

The same year Fujii et al. [Ref. 16] presented data condensing R-11 and ethanol on a single wire-wrapped smooth tube. Wire diameters of 0.1 mm, 0.2 mm, and 0.3 mm were used on copper tubes. They showed an increase in the outside heat transfer coefficient of 2 to 3 times that predicted by the

Nusselt equation for a smooth tube. This maximum enhancement of the outside heat transfer coefficient occurred at $P/D_w$ of 2. They also modeled the relationship between $P/D_w$ and the outside heat transfer coefficient enhancement and found reasonable agreement with their data.

Marto et al. [Ref. 17] showed enhancements in the outside heat transfer coefficient of up to 80% for a single wire-wrapped smooth copper tube over a plain smooth copper tube condensing steam (i.e. significantly lower than that found by Fujii [Ref. 16] for R-11). Their results showed an optimum $P/D_w$ between 5 and 7. Titanium wire diameters of 0.5 mm, 1.0 mm, and 1.6 mm were used, the difference in the results for R-11 and steam is the condensate retention between the wires for the case of steam. They then improved the model of Fujii et al. [Ref. 16] to account for the condensate retention and obtained reasonable agreement with there data.

Marto and Wanniarachchi [Ref. 19] tested smooth and roped titanium tubes, both with and without wire-wrap using steam in a tube bundle that could simulate up to 30 tubes in a vertical column. For the wire-wrapped tubes, a wire diameter of 1.6 mm was used. They reported that the mean bundle outside heat transfer coefficient could be significantly increased by using wire-wrapped tubes. Due to the fact that they are much less susceptible to the effects of condensate inundation.

## D. FILM CONDENSATION ON ROPED TUBES

Roped tubes lower the overall thermal resistance in several ways; first by promoting turbulent flow on the coolant side disrupting the laminar sublayer. Secondly, the rounded geometry and grooves on the outside surface of the tube set up low pressure regions which thin the condensate film over much of the tube's outer surface area (Figure 2). The grooves in the roped tube also make it easier for the condensate to drain off the tube. By thinning the film over most of the tube surface, the outside heat-transfer is enhanced.

The disadvantage of roped tubes is that the tubeside pressure drop is increased, so more pumping capacity is needed to provide the same coolant flow rate as with a smooth tube. The magnitude of this increased pressure drop is related to the groove depth and pitch. There is therefore always a trade-off between the increased heat transfer and the increased pressure drop, which can only be sorted out from an economic standpoint.

### 1. Summary of Roped Tube Condensation Data

In 1971, Withers and Young [Ref. 19] evaluated the use of roped tubes in a distillation plant condenser. They obtained enhancements of up to 50% in the overall heat transfer coefficient using the roped tubes with an equal pressure drop across the coolant side of the condenser. Catchpole and Drew [Ref. 20] tested various single roped

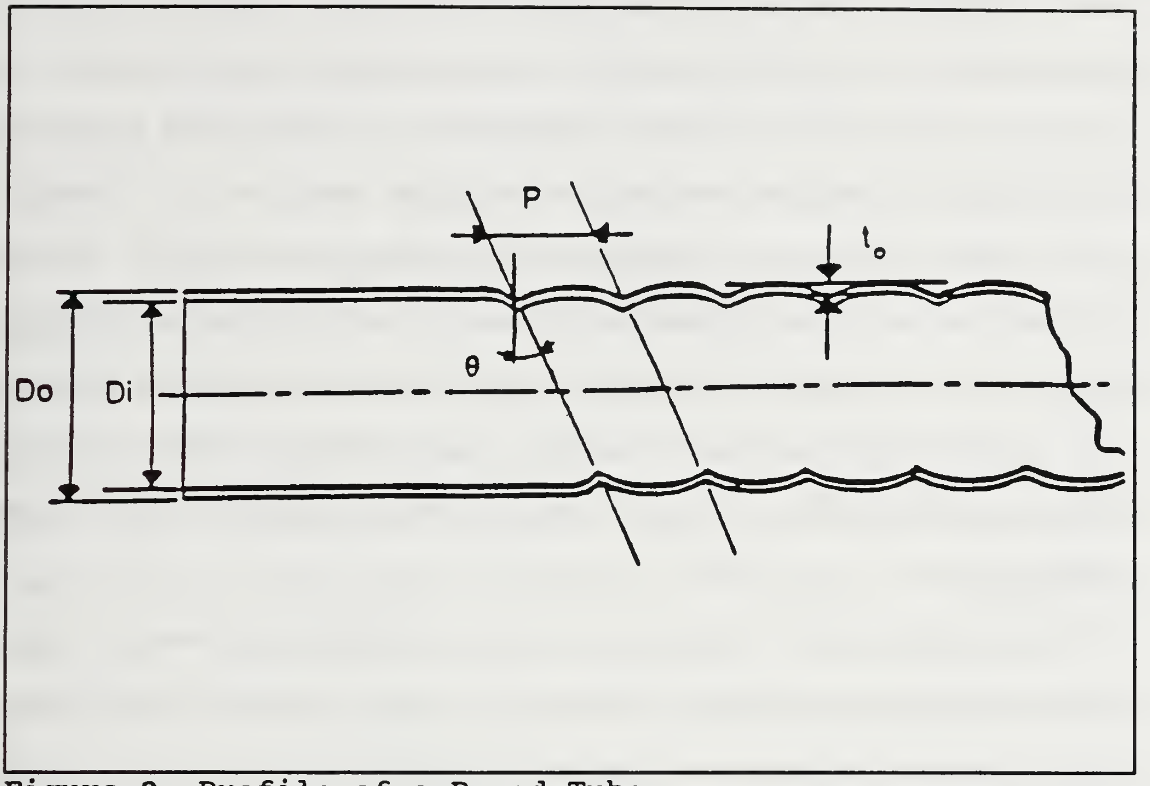

Figure 2. Profile of a Roped Tube

tubes. They varied the pitch and groove depth in the tubes and also obtained overall heat transfer improvements of up to 50%. There was always an enhancement with the roped tubes; the optimum tube for use, based on single tube data only, depended on a balance between space and weight requirements and higher operating cost due to the increased pumping power required.

Mehta and Rao [Ref. 21] tested roped aluminum tubes and were able to show that the outside heat transfer coefficient was enhanced between 16% and 38%, as compared to Nusselt theory for a smooth aluminum tube. Marto, Reilly, and Fenner [Ref. 22] tested eleven different roped tube configurations

(i.e. varying the groove pitch and depth) made of various materials. The tube was set up in a bundle arrangement to simulate a portion of a steam condenser. They found that the outside heat transfer coefficients, when compared to a smooth tube, were enhanced from 0.85 to 1.34 for the various tubes. The tubes with the highest performance had the deeper grooves and, as a consequence, larger coolantside pressure drops. They also noted that if the high performance tubes were not supported properly, there could be problems with tube vibration.

Cunningham et al. [Ref. 23, 24] studied the use of roped tube bundles in a steam condenser. They looked at two roped tubes with the same groove depth and pitch except one tube had six helical starts and the other tube had two helical starts. Their results showed that the roped tubes increased the overall heat transfer coefficient by 20% for the six start tube and up to 50% for the two start tube. The two start tubes showed higher performance for the top tube in the bundle, but lower tubes had problems with inundation. For the six start tubes, inundation did not have as large an effect as with the two start tubes, probably due to the better drainage. The six start tubes would therefore give the best overall performance when operating in a bundle.

In 1980, the Tennessee Valley authority retubed their Gallatin Steam plant Unit I condenser with 90-10 Cu-Ni LPD roped tubes and obtained an increase between 38% and 43% in

the overall bundle heat transfer coefficient, as compared to the original smooth tube bundle. However, the overall bundle heat transfer coefficient dropped as the tubes became fouled over a 2 to 4 month period. The fouling was removed by driving a stiff bristle brush through the tubes with high pressure air and water. After the fouling was removed, a 47% increase in the overall bundle heat transfer coefficient. (as compared to a smooth tube bundle) was observed [Ref. 3]. Mussalli and Gordon [Ref. 25] give a good review of the use of roped tubes in power plant condenser operations. Their paper points out that studies have shown the biofouling rate in smooth and roped tubes is approximately the same for the same water velocity. They also say that the tube enhancement may inhibit fouling buildup beyond a certain thickness due to the increased turbulence of the flow at the wall surface and that the use of chlorination treatment was effective at controlling biofouling in titanium tubes.

In summary, previous research conducted using wire-wrapped smooth and roped tubes in bundles have shown that the effects of condensate inundation can be significantly reduced. This thesis research has been conducted with a view to analyzing the enhancements in the outside heat transfer coefficient of wire-wrapped smooth and roped tubes and to determine if there is a relationship (with an optimum) between $P/D_w$ or F to the heat transfer enhancement.

# III. APPARATUS AND SYSTEM INSTRUMENTATION

## A. SYSTEM OVERVIEW

The apparatus used is the same as that used by Swensen [Ref. 5]. A schematic of the overall system is shown in Figure 3. Steam is generated from distilled water using ten 4 kW, 440 Volt Watlow immersion heaters in a 0.30m diameter Pyrex boiler. The steam passes from the boiler section up through a 2.13m (ID of 0.15m) straight length of Pyrex glass piping. It is then redirected 180 degrees by two 90 degree Pyrex glass elbows, and flows 1.52m down a straight length of Pyrex tubing into the stainless steel test section. The stainless steel test section contains the horizontally mounted condenser tube as shown in Figures 3 and 4. A circular viewing port in the test section allows the condensation process to be observed during testing. Any excess steam passes through the test section and into the auxiliary condenser unit. The auxiliary condenser is constructed of a single copper coil mounted to a stainless steel base at the bottom of a Pyrex glass condenser section. The condensed water is then returned to the boiler section by a gravity drain in the baseplate of the auxiliary condenser.

The auxiliary condenser is cooled by a continuous supply of tap water controlled by a throttle valve and flow meter.

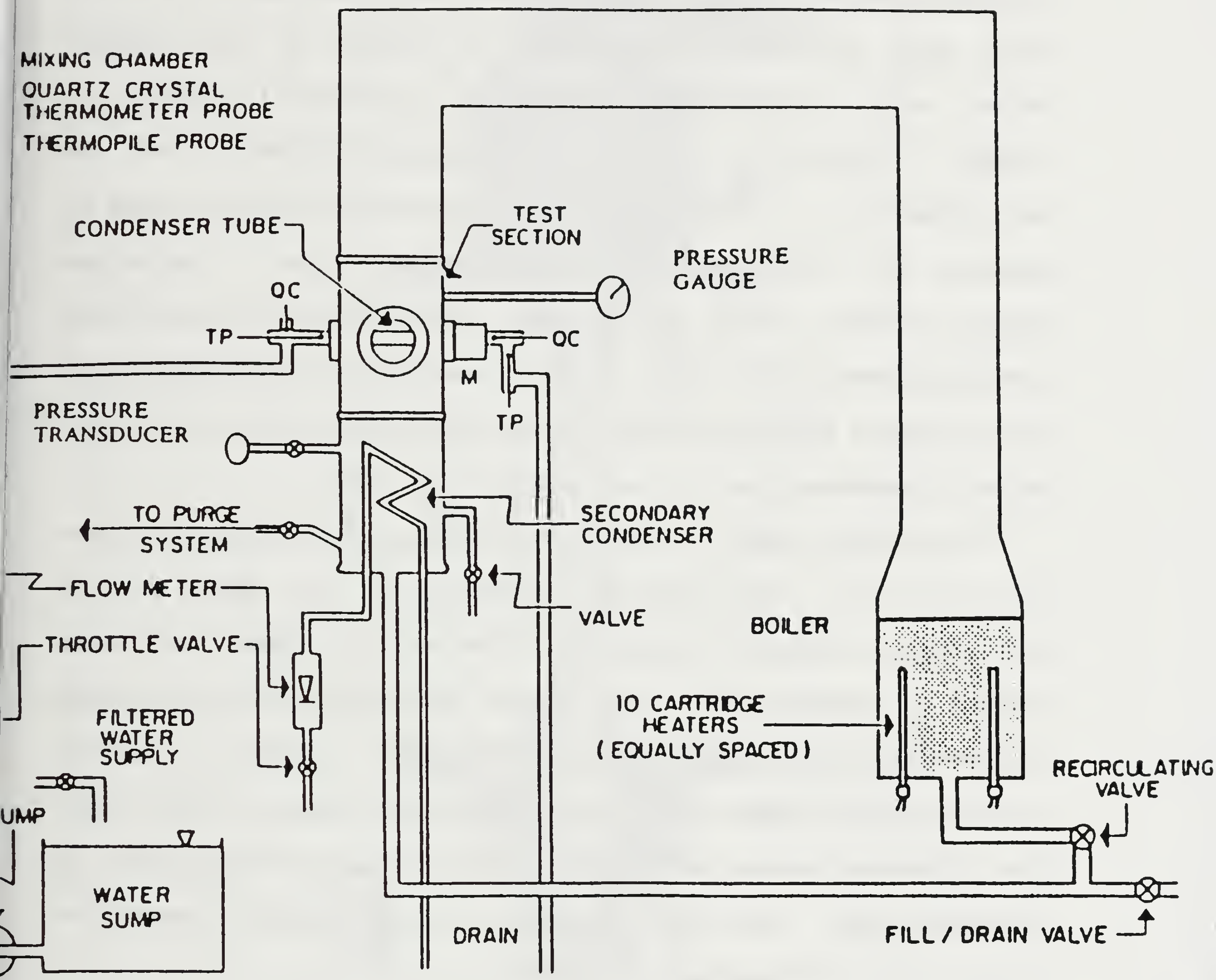


Figure 3. Schematic of the Single Tube Test Apparatus

Cooling water for the single horizontal tube is provided by a coolant system. This closed loop system consisted of a water sump tank, two centrifugal pumps in series, a flow control valve, and a calibrated flow meter as shown in Figure 3. Figure 4 shows the details of the test section and the arrangement of all the temperature measuring devices used to measure the temperature rise across the tube. The nylon mixing chamber mixes the flow at the outlet to ensure the average temperature of the flow is measured. The coolant flow rate through the horizontal tube can be varied to adjust the rate of condensation on the single test tube.

The system used to remove non-condensible gases is shown in Figure 5. The suction point is at the base of the auxiliary condenser where non-condensible gases are most likely to accumulate. The vacuum pump draws the air/steam mixture through an external condensing coil, which is located in the coolant sump tank, to condense any steam in the line. The condensed steam collects in a plexiglas container and is drained later. The air and other non-condensible gases are expelled to the atmosphere.

## B. SYSTEM INSTRUMENTATION

The electrical power input to the 440 $V_{AC}$ immersion heaters was controlled by a panel mounted potentiometer. The power calculation for the data acquisition system is described in detail by Poole [Ref. 26]. System pressure was monitored by

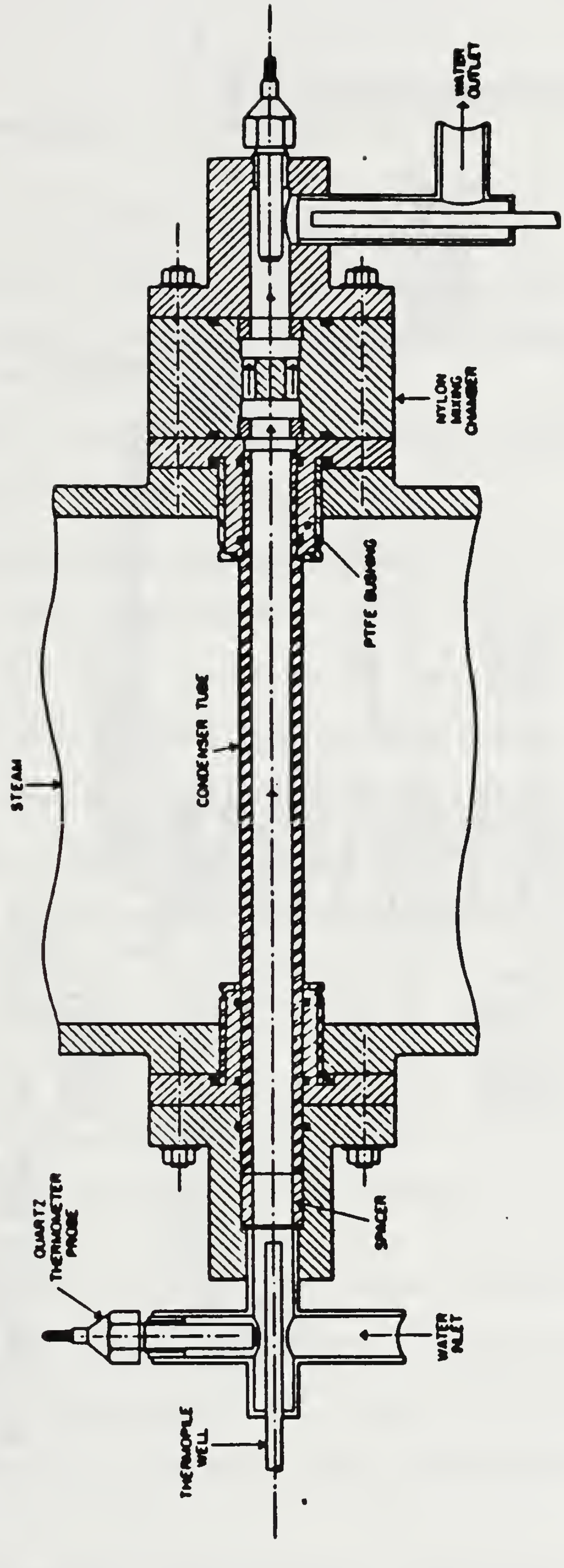


Figure 4. Schematic of the Test Section Insert

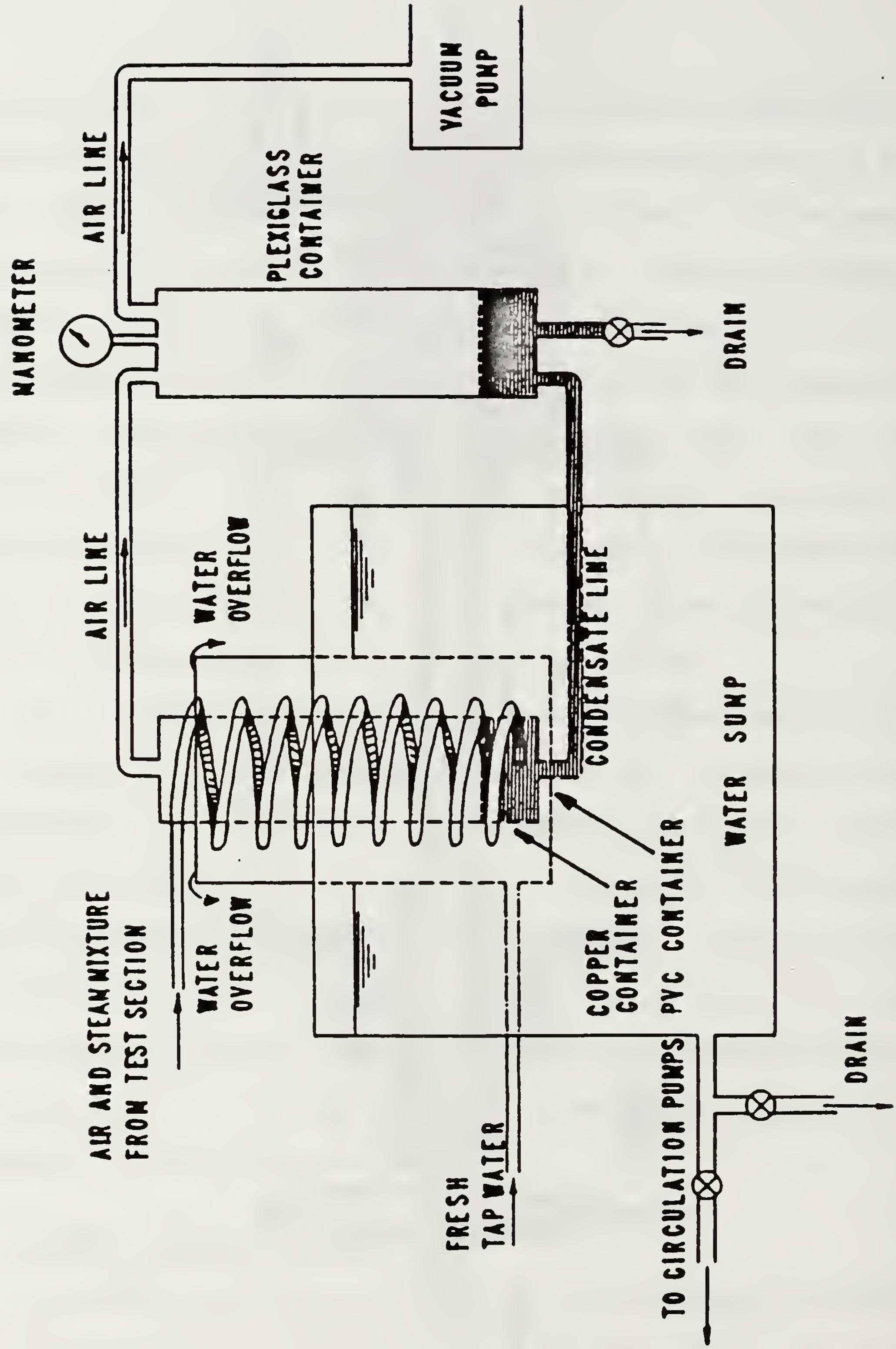


Figure 5. Schematic of Purging System and Cooling Water Sump

three different methods:

1. Setra model 204 pressure transducer.
2. System saturation temperature converted into pressure.
3. Heise solid front pressure gage (visual reading only).

The calibration for the pressure transducer and temperature instruments is given in Swensen [Ref. 5].

The system vapor temperature was measured by both a Teflon coated and a metal sheathed type-T copper/constantan thermocouple located just upstream of the test tube. The condensate return and ambient surrounding temperatures were measured with Teflon coated type-T copper/constantan thermocouples. The temperature rise of the coolant in the tube being tested was measured by three separate methods:

1. A single Teflon coated type-T copper/constantan thermocouple.
2. A ten-junction Teflon coated type-T copper/constantan thermopile.
3. An HP 2804A quartz crystal thermometer.

The relative positions of each of these three temperature measuring methods are shown in Figure 4. At the outlet of the tube, the coolant temperature is always measured after a coolant mixing chamber to ensure a well averaged temperature measurement.

All the data from the system instrumentation were processed using an HP-3497A data acquisition system controlled

by an HP-9826A computer. The raw data were processed and stored on computer disks. The data could then be reprocessed using a modified Wilson plot technique to obtain an outside heat-transfer coefficient (see section IV.C for details).

## C. TUBES TESTED

There were twelve tubes fabricated for this thesis. Some of the wire-wrapped smooth tubes were the same as used by Brower [Ref. 8], except they were altered to fit into the single tube apparatus used during this thesis. Listed in Table I are all the tubes that were tested and their associated dimensions. The tubes consisted of one smooth tube and seven wire-wrapped smooth tubes, all made of titanium. Three different wire diameters were used at various spacings on the tube, providing a range of wire pitch to wire diameter between 2 and 10. These are also listed in Table I. Commercially available titanium roped tubes (Wolverine KORODENSE LPD) were also tested, both with and without the three different wire diameters. The wires were placed in the corrugated grooves, giving the wires a fixed pitch. In addition, a smooth copper tube and two of the wire-wrapped copper tubes tested by Mitrou [Ref. 9] were tested (see Table I).

Table I. LISTING OF THE TUBES TESTED

| Tube No. | Tube Type | Wire Diameter (mm) | Wire Spacing (mm) | Wire Pitch (mm) | P/D Ratio | F | Outside Diameter (mm) | Inside Diameter (mm) | Tube Material |
|---|---|---|---|---|---|---|---|---|---|
| 0 | Smooth | None | None | None | None | 0 | 15.85 | 13.86 | Titanium |
| 1 | Smooth | 1.6 | 13.47 | 15.07 | 9.42 | 0.108 | 15.85 | 13.86 | Titanium |
| 2 | Smooth | 1.6 | 5.75 | 7.35 | 4.59 | 0.205 | 15.85 | 13.86 | Titanium |
| 3 | Smooth | 1.6 | 1.80 | 3.40 | 2.13 | 0.457 | 15.85 | 13.86 | Titanium |
| 4 | Smooth | 1.0 | 5.04 | 6.04 | 6.04 | 0.158 | 15.85 | 13.86 | Titanium |
| 5 | Smooth | 1.0 | 3.70 | 4.70 | 4.70 | 0.211 | 15.85 | 13.86 | Titanium |
| 6 | Smooth | 0.5 | 3.46 | 3.96 | 7.92 | 0.120 | 15.85 | 13.86 | Titanium |
| 7 | Smooth | 0.5 | 1.51 | 2.01 | 4.02 | 0.218 | 15.85 | 13.86 | Titanium |
| L | LPD | None | None | None | None | 0 | 15.85 | 13.47 | Titanium |
| L1 | LPD | 1.6 | 5.40 | 7.00 | 4.38 | 0.252 | 15.85 | 13.47 | Titanium |
| L2 | LPD | 1.0 | 6.00 | 7.00 | 7.00 | 0.152 | 15.85 | 13.47 | Titanium |
| L3 | LPD | 0.5 | 6.50 | 7.00 | 14.00 | 0.074 | 15.85 | 13.47 | Titanium |
| 50 | Smooth | None | None | None | None | 0 | 19.05 | 12.70 | Copper |
| 68 | Smooth | 1.0 | 3.91 | 3.91 | 3.91 | 0.269 | 19.05 | 12.70 | Copper |
| 71 | Smooth | 0.5 | 3.13 | 3.63 | 7.26 | 0.141 | 19.05 | 12.71 | Copper |

# IV. EXPERIMENTAL PROCEDURES AND DATA REDUCTION

## A. EXPERIMENTAL PROCEDURES AND OBSERVATIONS

Titanium and copper both have different wetting characteristics with respect to water. However, to ensure filmwise condensation, both types of tubes have been successfully treated with a sodium hydroxide and ethyl alcohol solution. This treatment has been used by several researchers in the past at NPS. Each tube was prepared in the following manner:

1. Both the inside and outside surfaces of the tube are cleaned using a mild soap and soft bristle brush. The tube is then rinsed first with distilled water, then with acetone, and again with distilled water to ensure there are no impurities on the surface of the tube. The second rinse should wet the entire surface of the tube with no breaks in the film. <u>NOTE:</u> the active surface area of the tube should not be handled during this procedure.

2. The tube is then placed over a steam bath.

3. Equal amounts of a 50% by weight sodium hydroxide solution and ethyl alcohol are mixed and kept warm to ensure a watery consistency is maintained.

4. The solution is then applied to the entire surface of the tube with a small brush every 10 minutes for one hour. If the tube has not been previously treated, apply the solution every 5 minutes for 20 minutes. A black oxide layer will form on the copper tubes. A layer forms on the titanium tubes, but they are not discolored.

5. The tube is then removed from the steam bath and rinsed with distilled water to remove the excess alcohol/sodium hydroxide solution. The tube should be held over the steam bath again to ensure that the entire tube surface wets easily as the steam condenses on it. The tube

should then be installed into the test section immediately afterward. Care should be taken when installing the tube into the test apparatus so the active surface of the tube is not disturbed.

The oxide layer that forms on the tube causes very good wetting characteristics on the surface of the tube. The oxide layer is very thin so it is assumed that it is negligible to the overall thermal resistance of the tube.

When the tube has been installed, the system is started up in accordance with the procedures given in Appendix B. Tests on the tubes were performed with either a HEATEX insert or no insert at all. The system is heated up to the desired operating condition, at either vacuum or atmospheric pressure, as outlined in the start-up procedure. The system needs to be maintained at equilibrium for at least thirty minutes prior to taking any data measurements. This is to ensure that the entire apparatus is warmed up. Data were taken at coolant flow rates (in %) of 80, 70, 60, 50, 40, 30, and 20, and then in steps of 10% back to 80%. Therefore, each point is checked twice at different times in the run to ensure repeatability. Several sample sets of data were evaluated to ensure the temperature difference across the tube, the saturation temperature, and the overall heat transferred were in equilibrium for each particular flow rate before the final data point was recorded. One data set took anywhere from ten to twenty minutes before the system was in equilibrium so a data set could be recorded.

Swensen [Ref. 5] describes how difficult it is to initiate filmwise condensation on a copper tube under vacuum pressure. To establish good filmwise condensation for a vacuum run, the following should be done:

1. Ensure coolant flow to the tube is secured. Then allow the apparatus vapor temperature (channel 40) to reach 3600-3800 microvolts.

2. Raise the auxiliary condenser flow rate to 50-60%, to cool the vapor temperature to ~3200 microvolts.

3. Secure the flow to the auxiliary condenser, and allow the vapor temperature to rise to 3700 - 3800 microvolts. This forms a steam blanket around the tube.

4. Initiate cooling water flow to the single tube being tested at a flow rate of at least 80%.

5. Restore flow to the auxiliary condenser to control vapor temperature and pressure. Observe the single tube through the viewing window to ensure good filmwise condensation has been established.

6. If some dropwise condensation persists, the steps above can be repeated. If dropwise condensation still continues, the tube should be removed and retreated with the ethyl alcohol and sodium hydroxide solution.

The wettablity of titanium and copper are different. It was much easier to obtain filmwise condensation on the titanium tubes than the copper tubes. Also, it appeared as if it was easier to initiate filmwise condensation on the enhanced tubes than the smooth tubes. Under vacuum conditions (pressures ≈12 kPa) at low cooling water flow rates, small patches of dropwise condensation could be seen on the bottom of the titanium tube at fairly regular intervals. These "dryout" patches appear to be the same as those described by

Swensen [Ref. 5] for the copper tube, and are believed to be caused by vortex shedding of the vapor around the tube. When the coolant flow rate was increased above 40%, there was enough condensate to spread out and cover the tube surface and the "dryout" patches did not occur.

## B. DATA REDUCTION PROCEDURES

The overall thermal resistance is represented by the sum of the coolant side resistance ($R_i$), the wall resistance ($R_w$), the fouling resistance ($R_f$), and the vapor side resistance ($R_o$). Since only clean tubes are used, the fouling resistance is negligible, ($R_f$=0). Therefore,

$$R_{total} = R_i + R_w + R_o \tag{4.1}$$

The coolant and vapor side resistances are convective in nature, so they need to be related to the areas:

$$R_i = \frac{1}{h_i A_i} \tag{4.2}$$

$$R_o = \frac{1}{h_o A_o} \tag{4.3}$$

where:

$R_i$ = inside resistance to heat transfer (K/W)

$h_i$ = inside heat transfer coefficient ($W/m^2K$)

$A_i$ = effective inside heat transfer area ($m^2$)

$R_o$ = outside resistance to heat transfer (K/W)

$h_o$ = outside heat transfer coefficient ($W/m^2K$)

$A_o$ = effective outside heat transfer area ($m^2$)

The effective area for the inside of the tube is represented by the entire length of the tube. The portions of the tube that are not exposed to steam act as fins, which will remove heat in the axial direction. The extended fin assumption and the associated fin efficiencies are used to account for the inlet and outlet portions of the tube. So, the effective inside area of the tube can be represented as:

$$A_i = \pi D_i(L+L_1\eta_1+L_2\eta_2) \tag{4.4}$$

where:

$D_i$ = inside diameter of the tube (m)

L = length of tube exposed to steam, active working length (m)

$L_1$ = length of the inlet portion of the tube (m)

$L_2$ = length of the outlet portion of the tube (m)

$\eta_1$ = fin efficiency of the inlet portion of the tube

$\eta_2$ = fin efficiency of the outlet portion of the tube

The effective outside surface area is dependent on the length of the tube exposed to steam, the active condensation length. The effective outside area is represented as:

$$A_o = \pi D_o L \tag{4.5}$$

The wall resistance assumes uniform radial conduction and is represented by the following equation:

$$R_w = \frac{\ln\left(\frac{D_o}{D_i}\right)}{2\pi L k_m} \tag{4.6}$$

where:

$R_w$ = tube wall resistance (K/W)

$D_o$ = outside diameter of the tube (m)

$D_i$ = inside diameter of the tube (m)

$k_m$ = thermal conductivity of the wall material (W/mK)

The overall thermal resistance can be related to the overall heat transfer coefficient ($U_o$) and the effective outside area ($A_o$) by:

$$R_{total} = \frac{1}{U_o A_o} \tag{4.7}$$

where:

$U_o$ = overall heat transfer coefficient (W/m$^2$K)

Substituting equations (4.2), (4.3), and (4.7) into (4.1) gives:

$$\frac{1}{U_o A_o} = \frac{1}{h_i A_i} + R_w + \frac{1}{h_o A_o} \tag{4.8}$$

The total heat transfer rate to the single tube can be calculated from an energy balance by using the temperature difference of the cooling water across the tube and the mass flow rate of the coolant through the tube:

$$Q = \dot{m}C_p(T_2 - T_1) \qquad (4.9)$$

The overall heat transfer coefficient can then be calculated from:

$$Q = U_o A_o (LMTD) \qquad (4.10)$$

where:

$$LMTD = \frac{(T_2 - T_1)}{\ln\left[\frac{T_{sat} - T_1}{T_{sat} - T_2}\right]} \qquad (4.11)$$

where:

$Q$ = total heat transfer rate (W)

$m$ = mass flow rate of the coolant (kg/s)

$C_p$ = Specific heat of coolant at constant pressure (J/kgK)

LMTD = log mean temperature difference

$T_1$ = inlet coolant temperature (K)

$T_2$ = outlet coolant temperature (K)

$T_{sat}$ = vapor saturation temperature (K)

The inlet and outlet cooling water temperatures were measured with a quartz thermometer and the saturation temperature was measured using the vapor thermocouple (channel 40). In addition, a correction factor was used to account for the viscous heating of the coolant through the tube; there correction equations are shown in Appendix A.

Once the total heat transfer rate has been calculated, the overall heat transfer coefficient can be calculated by using equation (4.10). Now only two unknowns remain, the inside heat transfer coefficient, $h_i$, and the outside heat transfer coefficient, $h_o$. These are computed using the modified Wilson plot technique.

## C. MODIFIED WILSON PLOT TECHNIQUE

The most accurate way to obtain inside and outside heat transfer coefficients is to measure the vapor temperature, mean wall temperature, and the coolant temperature directly. The coolant and vapor temperatures can be easily measured. However, to measure the tube wall temperature an, instrumented tube (with thermocouples embedded in the wall) must be used. With the instrumented tube, the inside and outside heat transfer coefficients can be calculated directly. Unfortunately, the manufacturing of instrumented tubes is costly and time consuming. Also, instrumented tubes would be impractical if a large number of tubes are to be tested.

An alternative to using an instrumented tube is to solve for both the outside and inside heat transfer coefficients simultaneously using the modified Wilson plot technique. A detailed outline of the technique is given by Marto [Ref. 27].

The modified Wilson plot technique relies on the fact that the overall heat transfer coefficient can be reliably measured from experimental data. Two forms of equations need to be

selected for the inside and outside heat transfer coefficients. In this thesis, the outside heat transfer coefficient is represented by the equation of Nusselt [Ref. 10] based on $\Delta T$:

$$h_o = \alpha \left[ \frac{k_f^3 \rho_f^2 g h_{fg}}{\mu_f D_o \Delta T_f} \right]^{1/4} = \alpha Z \tag{4.12}$$

where:

$\alpha$ = dimensionless Nusselt coefficient

$k_f$ = thermal conductivity of the condensate film (W/mK)

$\rho_f$ = density of the condensate film (kg/m$^3$)

$\mu_f$ = dynamic viscosity of the condensate film (kg/ms)

$h_{fg}$ = specific enthalpy of vaporization (J/kg)

$\Delta T_f$ = temperature difference across the condensate film (K)

g = gravitational constant (9.81 m/s$^2$)

We also had the option of using Fujii's [Ref. 12] correlation, equation (2.4), for the outside heat transfer coefficient in the program used to evaluate the data. The inside heat transfer coefficient can be represented by one of several correlations. The general form for the inside heat transfer coefficient is:

$$h_i = C_i \Omega \tag{4.13}$$

where $\Omega$ varies with the particular correlation used.

Using the Sieder-Tate correlation [Ref. 6]:

$$\Omega = \frac{k_c}{D_i} Re^{x} Pr^{1/3} \left(\frac{\mu_c}{\mu_w}\right)^{0.14} \tag{4.14}$$

where x, the exponent to the Reynolds number, can be varied in the program evaluating the data.

Using the Sleicher-Rouse correlation [Ref. 28]:

$$\Omega = \frac{k_c}{D_i}(5 + 0.015 Re_f^{c} Pr_w^{d}) \tag{4.15}$$

where:

$$c = 0.88 - \frac{0.24}{4 + Pr_w}$$

$$d = \frac{1}{3} + 0.5 e^{-0.6 Pr_w}$$

Using the Petukhov-Popov correlation [Ref. 29]:

$$\Omega = \frac{k_c}{D_i}\left[\frac{\left(\frac{\epsilon}{8}\right) Re\, Pr}{K_1 + K_2\left(\frac{\epsilon}{8}\right)^{1/2} (Pr^{2/3} - 1)}\right] \tag{4.16}$$

where:

$$\epsilon = [1.82\log(Re) - 1.64]^{-2}$$

$$K_1 = 1 + 3.4\epsilon$$

$$K_2 = 11.7 + 1.8\,Pr^{-\frac{1}{3}}$$

Substituting equations (4.12) and (4.13) into equation (4.8) gives the following:

$$\left[\frac{1}{U_o} - R_w A_o\right] Z = \frac{A_o Z}{C_i\,\Omega\,A_i} + \frac{1}{\alpha} \tag{4.17}$$

Letting:

$$Y = \left[\frac{1}{U_o} - R_w A_o\right] Z \tag{4.18}$$

and

$$X = \frac{A_o Z}{A_i\,\Omega} \tag{4.19}$$

a simplified linear equation results:

$$Y = mX + b \tag{4.20}$$

where

$$m = \frac{1}{C_i} \tag{4.21}$$

and

$$b = \frac{1}{\alpha} \qquad (4.22)$$

the parameters $\Omega$ and Z are temperature dependent, so an iterative procedure must be used to solve the equation. A least squares fit of equation (4.17) is used to determine $C_i$ and $\alpha$. The inside heat transfer coefficient can then be determined using equation (4.13). Since $h_i$ and $U_o$ are both known, the outside heat transfer coefficient can be solved using equation (4.8).

It should be noted that the accuracy of the modified Wilson plot technique is dependent on the number of data points evaluated, as well as the range of flow rates used. The current computer system does not allow different run files to be combined to evaluate a tube. Each file has to be processed separately. This leads to scatter between the data runs for the values of $\alpha$ and $C_i$ between runs for the same types of tube.

## D. ENHANCEMENT RATIO

From Nusselt theory, it can be shown that:

$$q = a\,\Delta T_f^n \qquad (4.23)$$

where:

$$a = \alpha\left[\frac{k_f^3\,\rho_f^2\,g\,h_{fg}}{\mu_f D_o}\right]^{1/4}$$

q = the heat flux based on the outside area ($W/m^2$)

$\Delta T_f$= the temperature drop across the condensate film (K)

We also know that the heat flux can be represented by:

$$q = h_o \Delta T_f \tag{4.24}$$

So, the outside heat transfer coefficient can be represented by:

$$h_o = a \Delta T_f^{n-1} \tag{4.25}$$

From Nusselt theory, n = 0.75, so the enhancement ratio, based on a constant temperature drop across the condensate film, can be expressed as:

$$E_T = \frac{h_{oe}}{h_{os}} = \frac{a_e}{a_s} = \frac{\alpha_e}{\alpha_s} \tag{4.26}$$

where the subscripts of e and s refer to enhanced and smooth tubes respectively.

# V. RESULTS AND DISCUSSION

## A. INSIDE HEAT TRANSFER CORRELATION

Previous to this thesis, Swensen [Ref. 5] gave a discussion of how the inside heat transfer coefficient has been found at NPS. He used an instrumented tube to collect data at atmospheric pressure and empirically derived two variants of the Sieder-Tate correlation to express the inside heat transfer coefficient for a medium size copper tube ($D_i$ = 12.7 mm). These correlations were represented as:

Using a HEATEX insert:

$$Nu = 0.22\, Re^{0.69}\, Pr^{1/3} \left(\frac{\mu_c}{\mu_w}\right)^{0.14} \tag{5.1}$$

Using No insert:

$$Nu = 0.013\, Re^{0.89}\, Pr^{1/3} \left(\frac{\mu_c}{\mu_w}\right)^{0.14} \tag{5.2}$$

Swensen developed the new correlations because it was thought that the inlet arrangement (a 90 degree bend just prior to the inlet of the tube) was affecting the correlation used to solve for the outside heat transfer coefficient. Almost all of Swensen's data were taken at atmospheric pressure using a HEATEX insert. When this thesis effort started, equations (5.1) and (5.2) were used to evaluate the inside heat transfer

coefficient. These two new correlations should provide comparable results for the outside heat transfer coefficient to those obtained by Swensen [Ref. 5]. The tubes studied in this thesis have a different inside diameter (13.86 mm) and are made from titanium and not copper.

Figures 6 and 7 show the values of the outside heat transfer coefficient for both the titanium and copper tubes at atmospheric and vacuum pressures using equations (5.1) and (5.2) in the data reduction scheme. At atmospheric pressure, Figure 6 shows Swensen's equations work well for the copper tubes; however, the results for the titanium tubes do not agree with Swensen's data well at all. In fact, a reduction of the outside heat transfer coefficient is shown for the HEATEX insert data as the temperature difference across the condensate film decreases, which is contrary to what was expected. At vacuum pressure, Swensen's equations show that the outside heat transfer coefficient curve is flatter than what is given by the instrumented copper tube data; also, the data shows much more scatter. There are several reasons this may have occurred. The first is that the leading coefficients for both correlations are fixed, so a change in the geometry (diameter) may have affected the results using these correlations. Consequently, the leading coefficient was left to 'float' to try and account for these differences. When the data were then reprocessed, the coefficient dropped by 30% for the HEATEX insert data. This drop in the leading coefficient

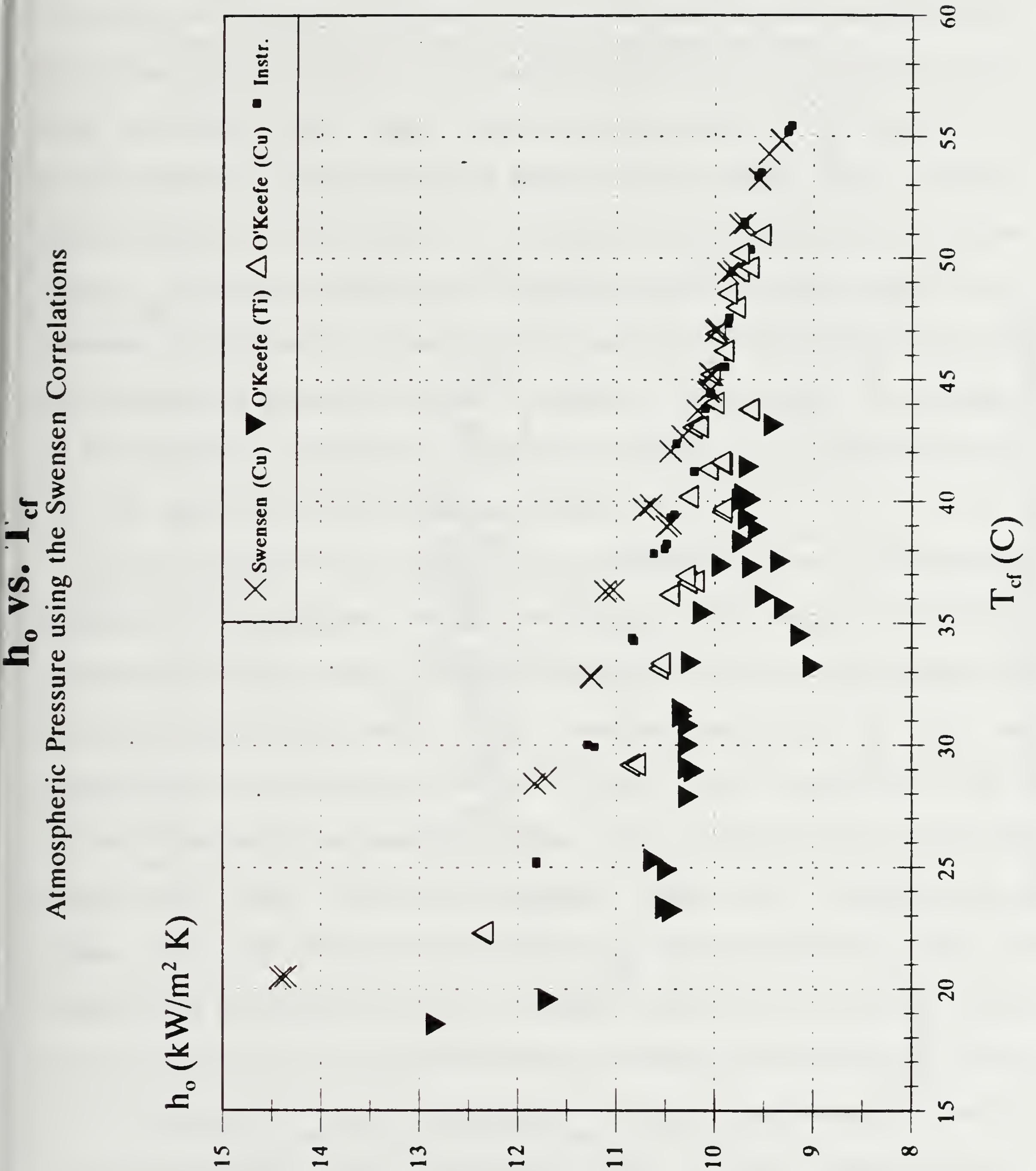


Figure 6. Comparison of Results for the Outside Heat Transfer Coefficient at Atmospheric Pressure Using the Swensen Correlations

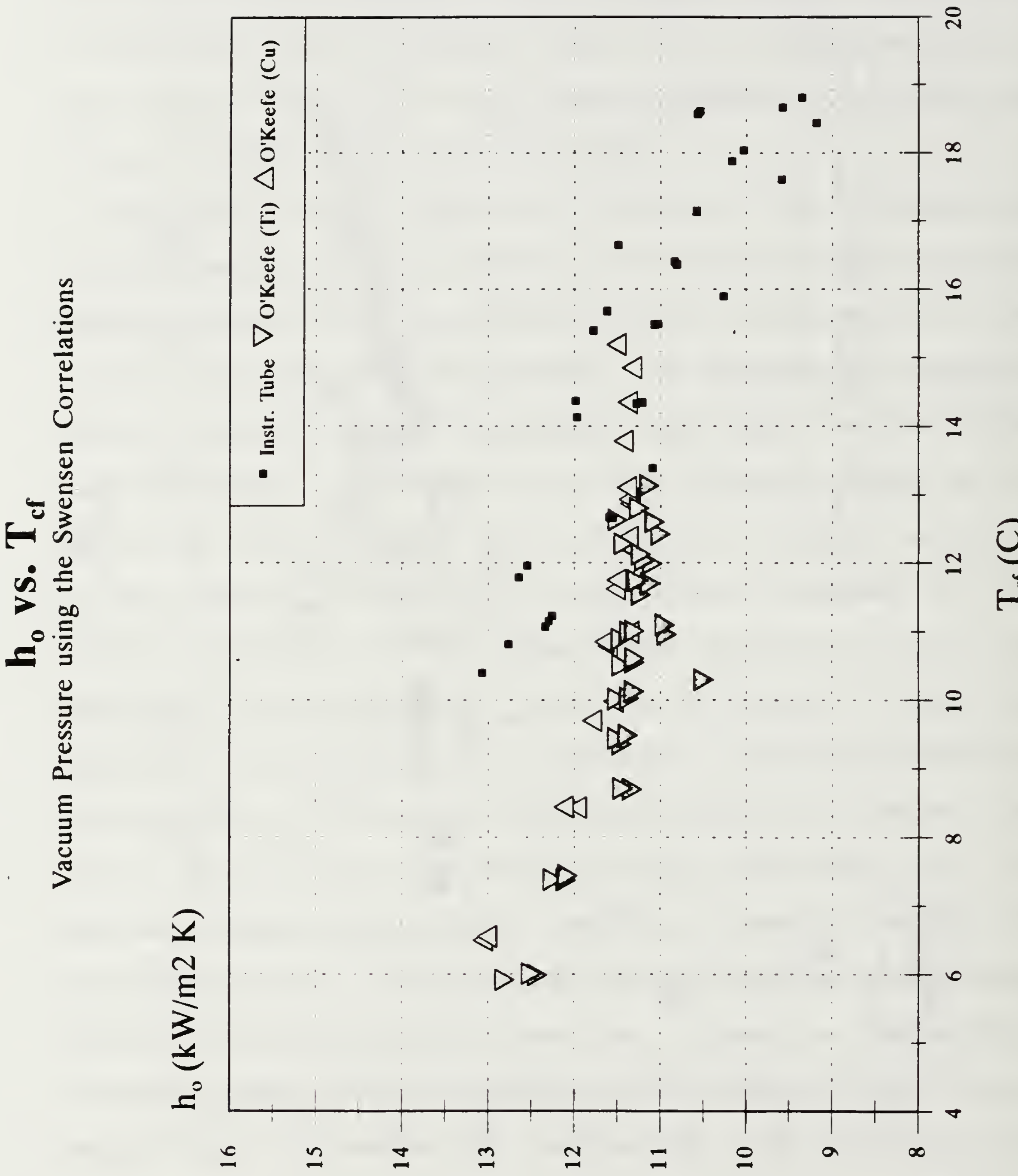


Figure 7. Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure using the Swensen Correlations

was much larger than expected, bringing into question the validity of Swensen's correlations for the titanium tube data. The other significant difference between the titanium tube data and the copper tube data is the range of $\Delta T_f$,which is much lower for the titanium tube. The copper tube with the HEATEX insert had higher $\Delta T_f$ values for similar coolant flow rates. Swensen produced his correlations for the range of $\Delta T_f$ covered by his data. They do not seem to perform well outside this range as seen in Figures 6 and 7. Therefore, it appears as if the data reduction scheme recommended by Swensen should not be used for the titanium tubes.

In an effort to correct the problem, other inside heat transfer correlations were considered. The Argonne National Laboratory (ANL) [Ref. 31] conducted a thorough assessment of several different inside heat transfer correlations for low temperature turbulent water flows to determine which correlation was the most accurate. The conclusions of the ANL study were that the Petukhov-Popov [Ref. 30] and Sleicher-Rouse [Ref. 29] correlations were the most accurate (± 5%) in predicting the inside heat transfer coefficient, over a range of Pr=6.0 to 11.6. Both the Petukhov-Popov and Sleicher-Rouse correlations are given in Chapter IV.C and are based on having a long straight inlet section prior to the test section. Swensen identified these correlations as the most accurate but he felt that he could not use them because of the sharp bend

in the inlet flow arrangement for the test apparatus as previously mentioned.

Both Petukhov-Popov and Sleicher-Rouse correlations were then used except that a floating leading coefficient was inserted to account for the different inlet to the test section, as shown in equations (4.13), (4.15), and (4.16). Figure 8 presents the same data shown in Figure 6 for atmospheric pressure, except they have been reprocessed using the Petukhov-Popov correlation for the inside heat transfer coefficient. It can be seen that the agreement between the titanium and copper tubes is much better in this case. Furthermore, the agreement with the instrumented tube data is much better, consistently within ± 7%. Uncertainty bands are shown on this figure, and the scatter is well within the predicted uncertainty. In the same way, Figure 9 shows the same data as in Figure 7 at vacuum pressure, except the data have been reprocessed using the Petukhov-Popov correlation for the inside heat transfer coefficient. Again the results show that the titanium and copper tube data compare much better with the instrumented tube data. Again the scatter is within the uncertainty of the data. Figure 10 compares the use of the Petukhov-Popov and Sleicher-Rouse correlations and it shows similar results are obtained when the Sleicher-Rouse correlation is used in evaluating the inside heat transfer coefficient. The ANL [Ref. 31] paper said:

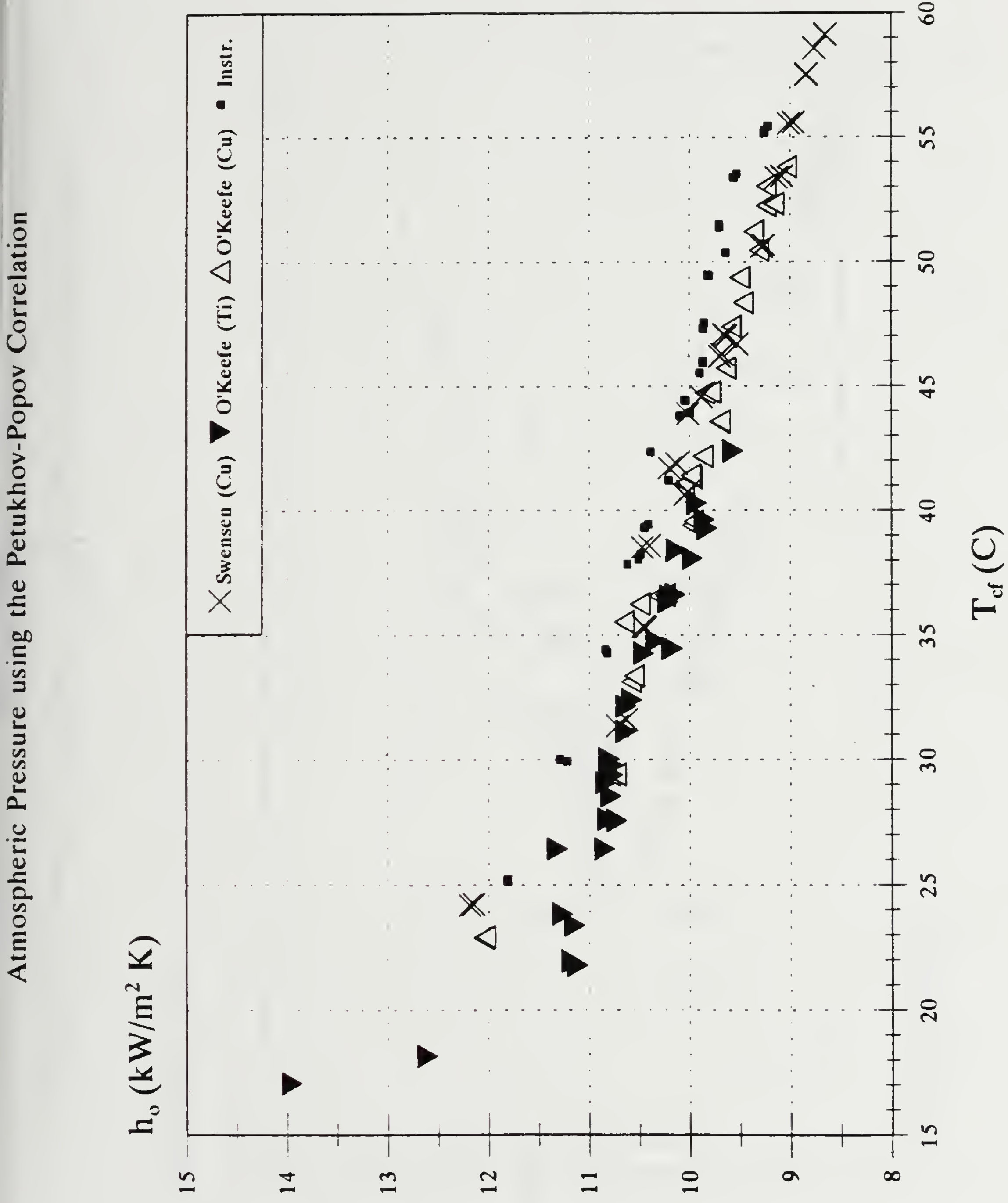


**Figure 8.** Comparison of the Outside Heat Transfer Coefficients at Atmospheric Pressure using the Petukhov-Popov Correlation

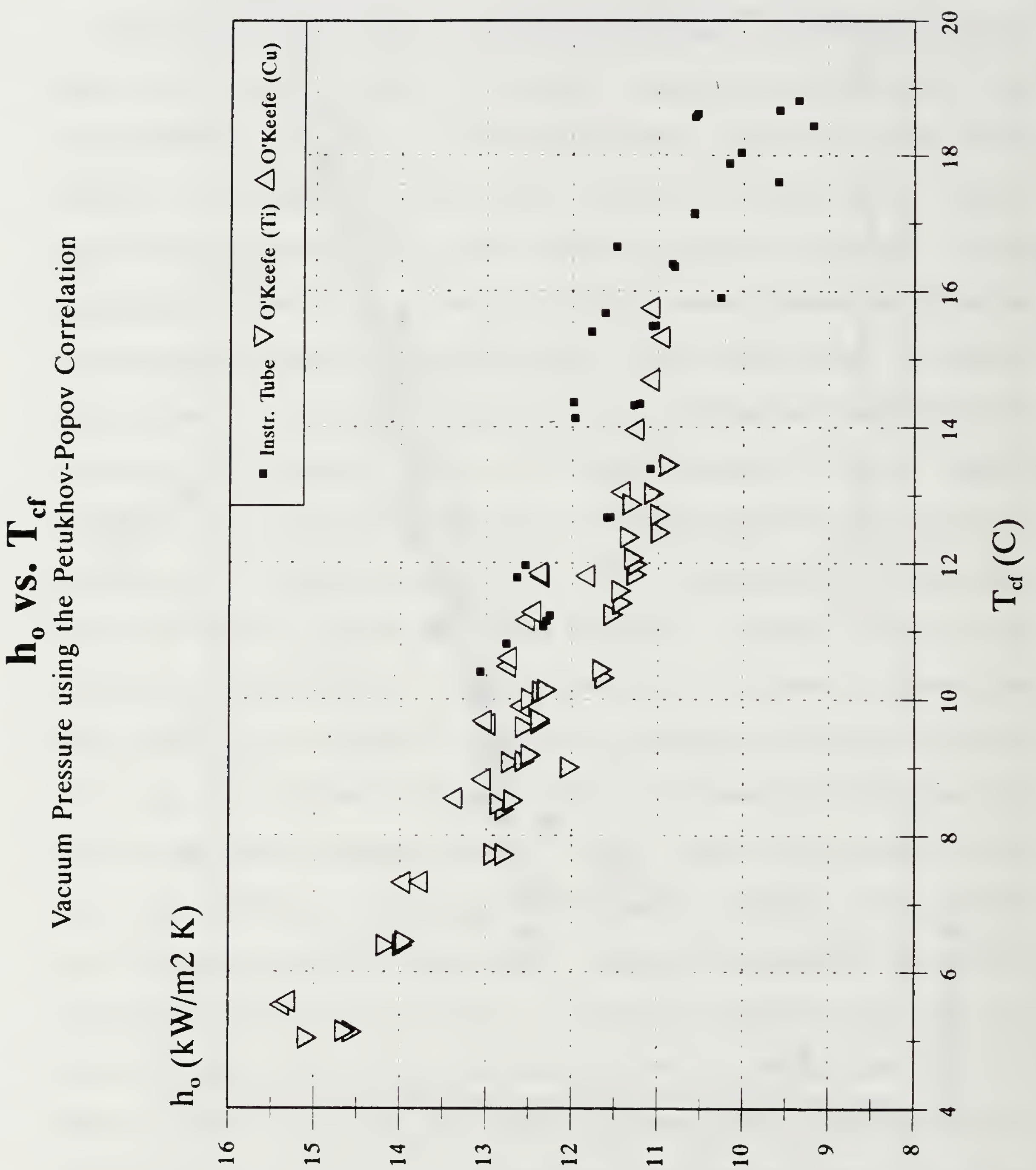


Figure 9. Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure Using the Petukhov-Popov Correlation

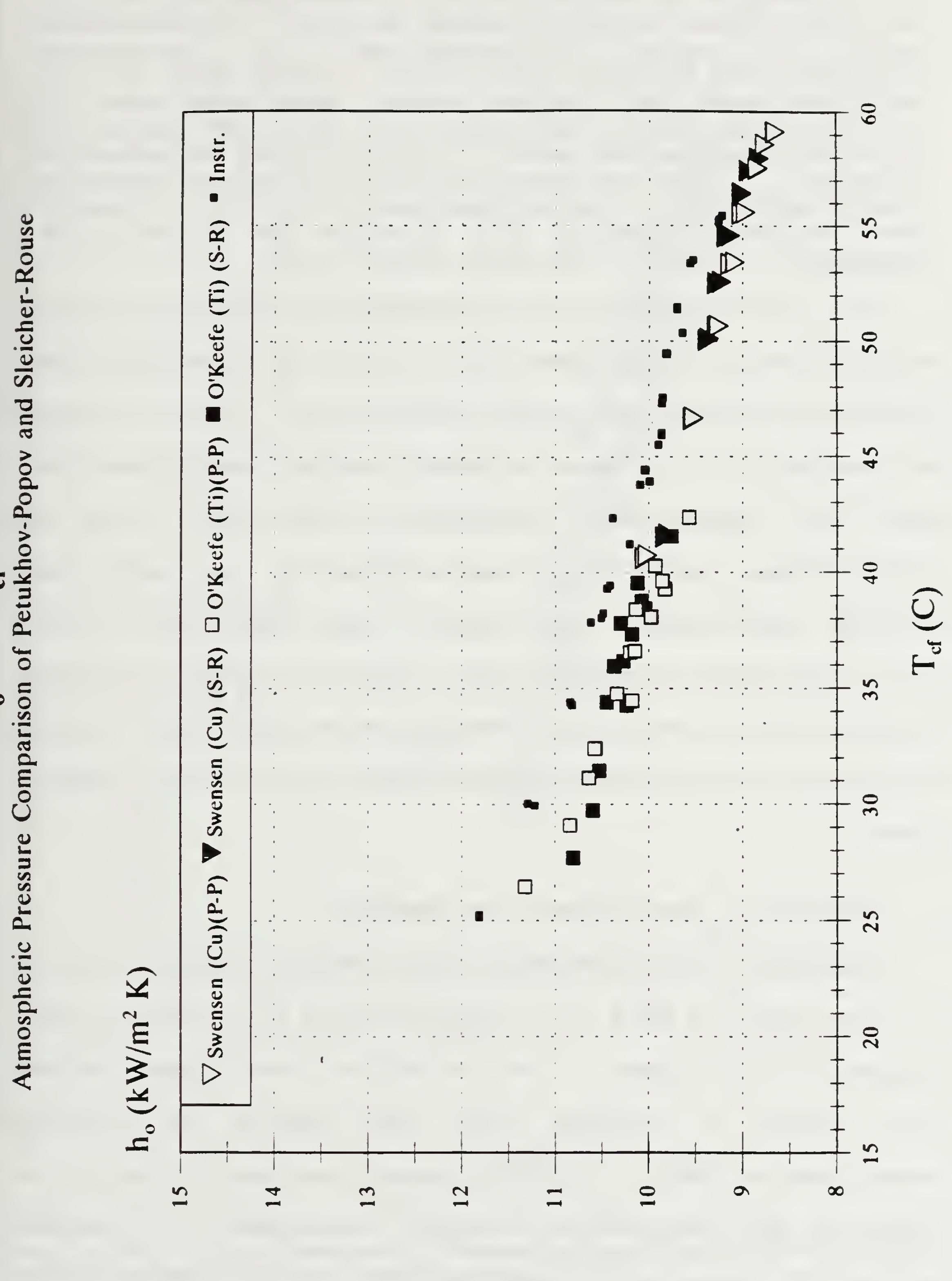


Figure 10. Comparison if the Inside Heat Transfer Coefficients using the Petukhov-Popov and Sleicher-Rouse Correlations

> It is tempting to follow the "old technology" and utilize n = 0.80 as the Reynolds number exponent, in accordance with the popular Dittus-Boelter and Sieder-Tate correlations. However, more recent correlations, such as Petukhov-Popov and Sleicher-Rouse, have been shown to exhibit much better agreement with the most carefully obtained experimental data ... In the Pr and Re ranges of interest ... these correlations yield "effective" Reynolds number exponents in the neighborhood of n = 0.85. Thus it was decided to employ n = 0.85 in the Wilson plot procedure to generate nominal values of $h_i$.

With this information, the Sieder-Tate equation was then evaluated using an exponent of 0.85 for the Reynolds number and again floating the leading coefficient. Figure 11 shows the results for the outside heat transfer coefficient when using the Sieder-Tate correlation (with $Re^{0.85}$) and the Petukhov-Popov correlation for determining the inside heat transfer coefficient. The results show that there is very little difference between using these two quite different correlations for the inside heat transfer coefficient, giving confidence in the data reduction technique for the titanium tubes.

## B. ANALYSIS OF THE SMOOTH TUBE RESULTS

A series of runs were made using a smooth titanium tube to get some baseline data for comparison with the enhanced wire-wrapped titanium tubes. A smooth medium sized copper tube was also tested to compare with the results of previous researchers at NPS. A HEATEX insert was used to boost the values of the inside heat transfer coefficient and thereby improve the measured accuracy of the outside heat transfer

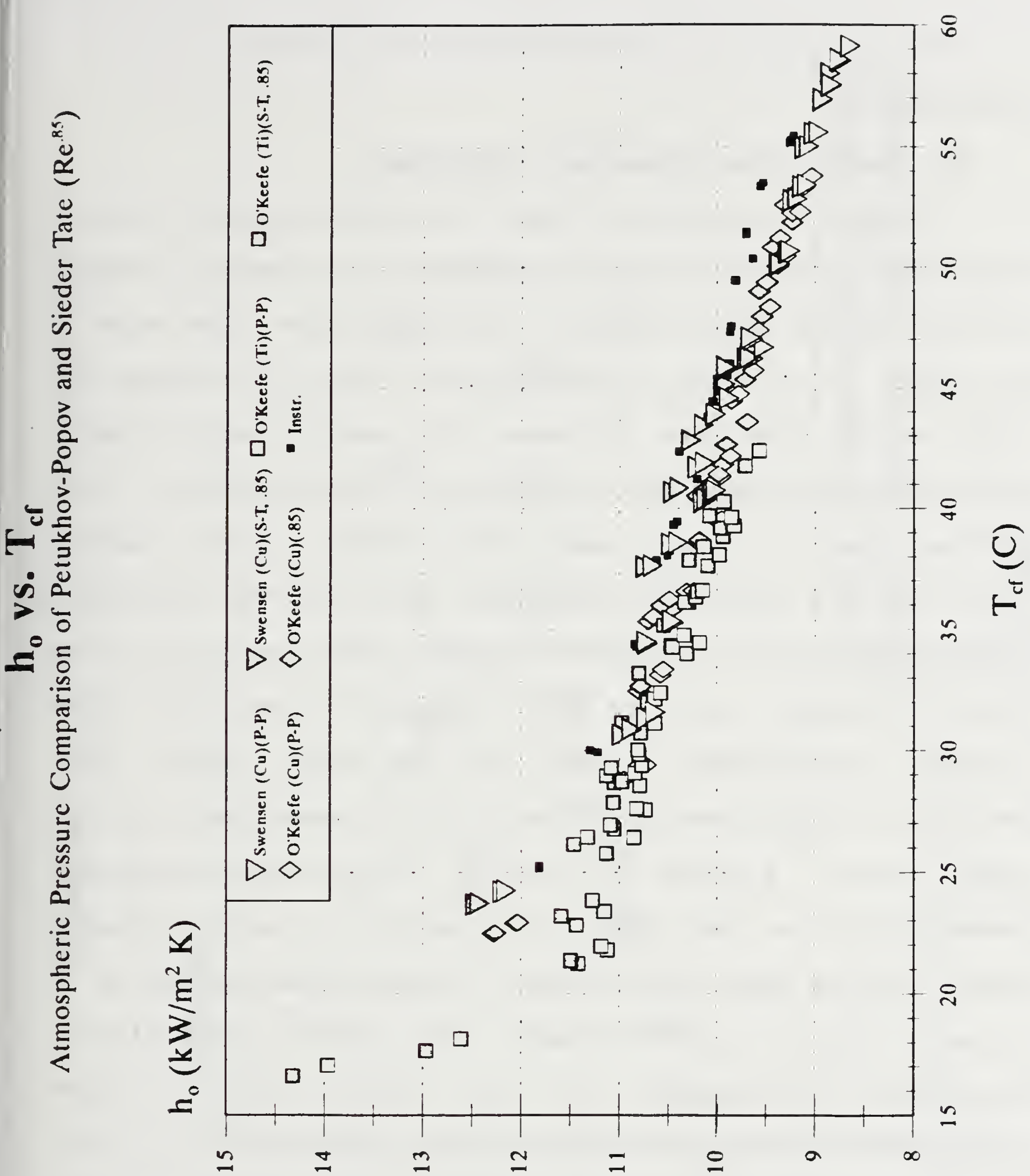


Figure 11. Comparison of the Outside Heat Transfer Coefficients for Atmospheric Pressure Using the Petukhov-Popov and Sieder-Tate ($Re^{.85}$) Correlations

coefficient.

### 1. Overall Heat Transfer Coefficient

Figures 12 through 15 show the overall heat transfer coefficient values for each atmospheric and vacuum pressure run done on the smooth titanium and copper tube. The shape of the curve is related to the coolant flow rate through the tube; as the flow rate increases the overall heat transfer coefficient increases due to improved coolant mixing. It is obvious that in every case, the overall heat transfer coefficient is higher for the copper tube (≈18% for the HEATEX insert data and ≈14% for the no insert data at a coolant flow rate of 2.5 m/s). Most of this increase in the overall heat transfer coefficient is due to the much smaller wall resistance (approximately a factor of 6) associated with the copper tube. Figures 12 through 15 also show excellent repeatability of the data. The effect of using a Heatex insert can be seen in Figure 16, which shows values of $U_o$ averaged for all the data taken. The HEATEX insert gives a significant enhancement in the overall heat transfer coefficient of around 20% for a coolant flow rate of 2.25 m/s. The vapor shear forces also effect the overall heat transfer coefficient ($U_o$). It can be seen that $U_o$ is higher for the vacuum runs ($U_\infty \approx 2$ m/s) than the atmospheric runs ($U_\infty \approx 1$ m/s) because of the higher vapor shear effect. However, this vapor shear effect is small (≤5%) when compared to the effect that

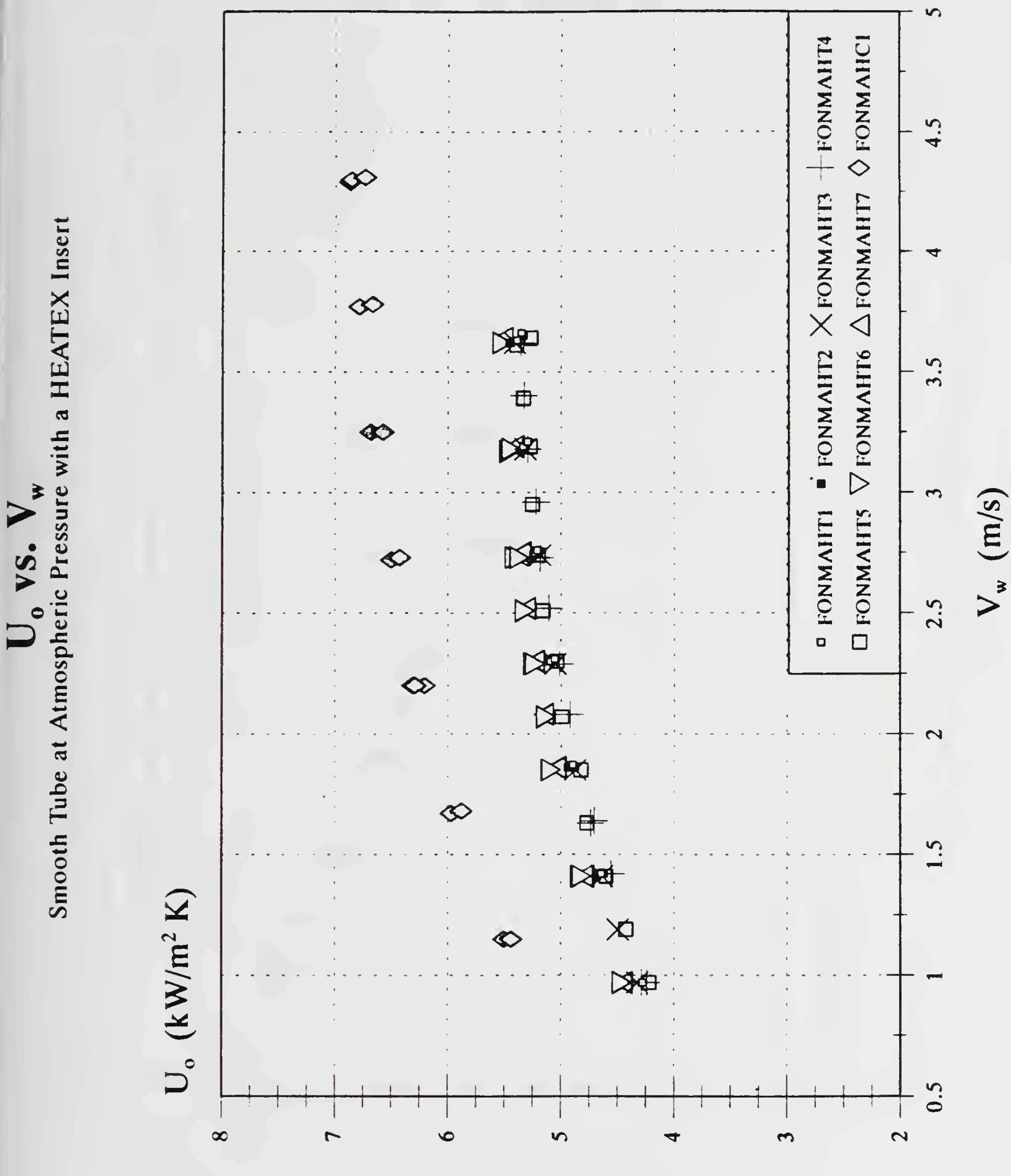


Figure 12. $U_o$ vs. $V_w$ for a Smooth Tube at Atmospheric Pressure with a HEATEX Insert

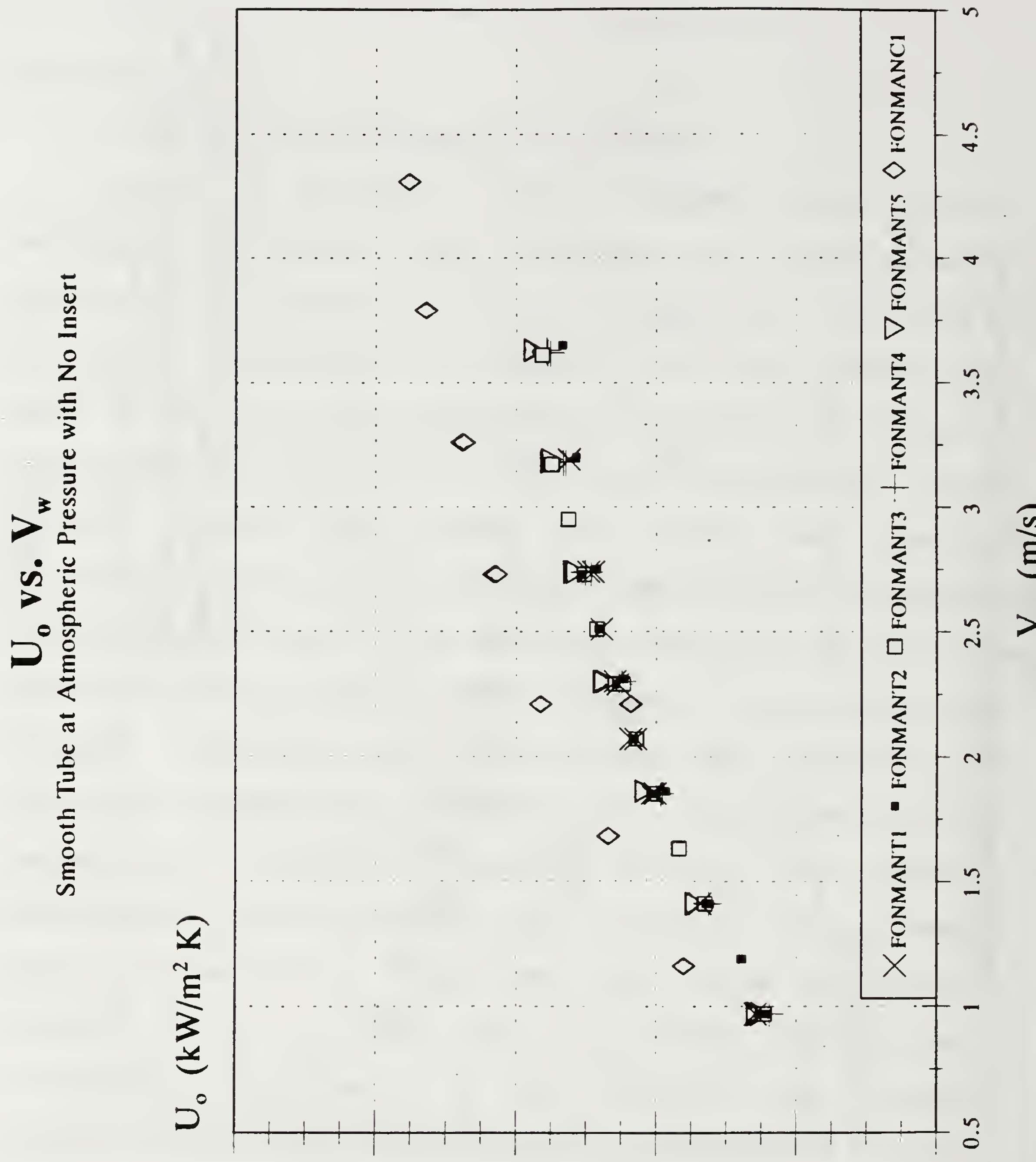


Figure 13. $U_o$ vs. $V_w$ for a Smooth at Atmospheric Pressure with No Insert

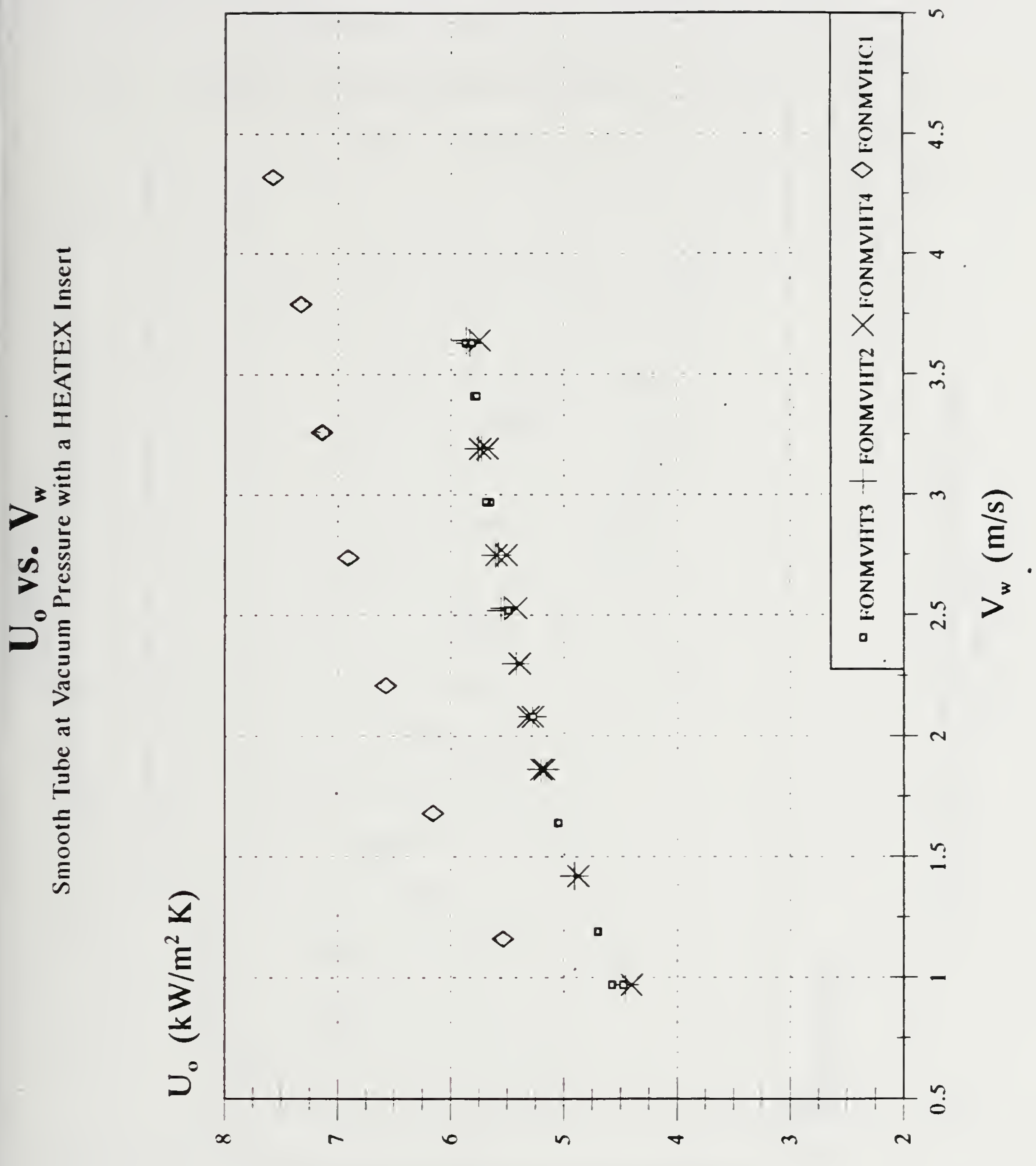


Figure 14. $U_o$ vs. $V_w$ for a Smooth Tube at Vacuum Pressure with a HEATEX Insert

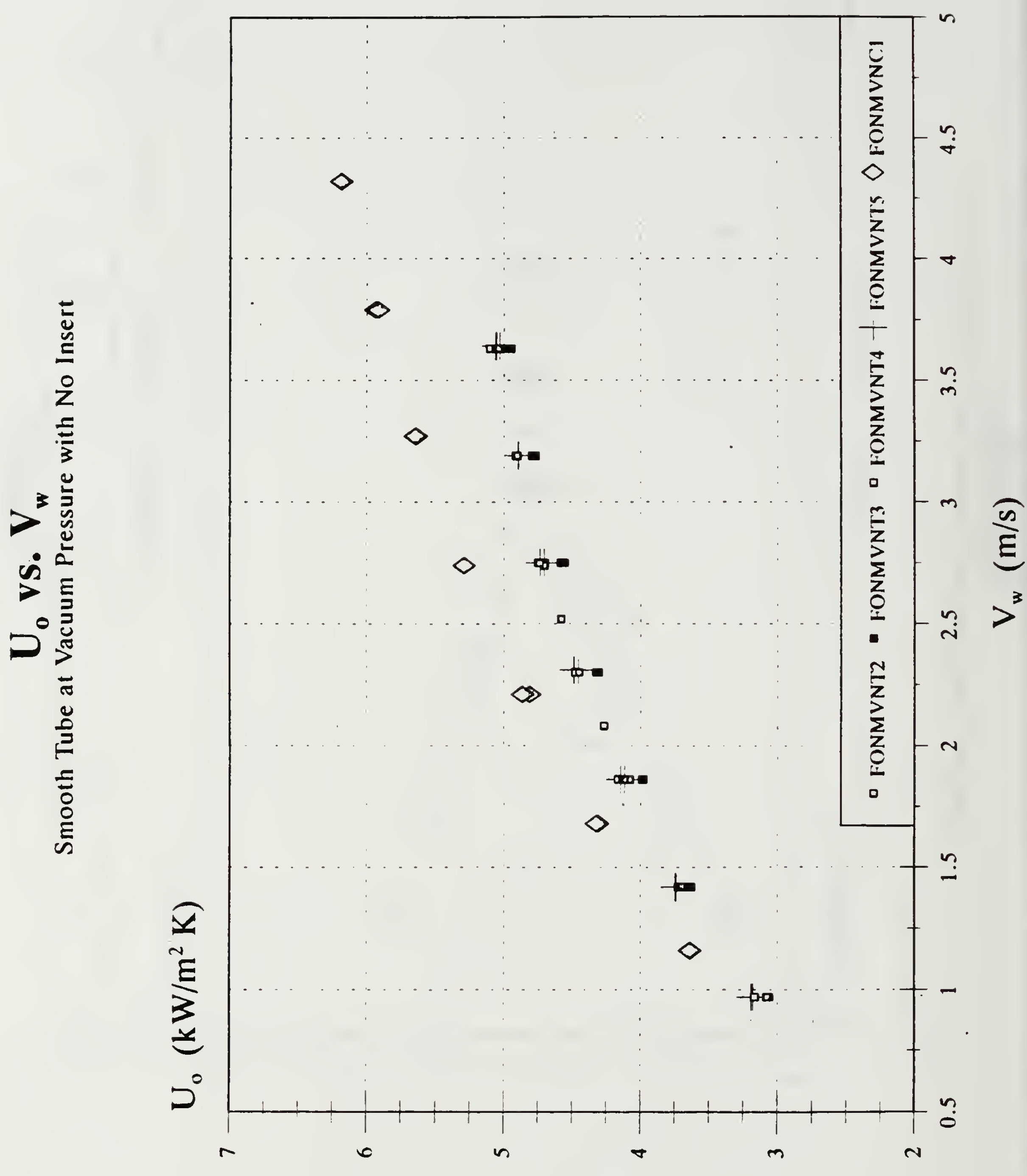


Figure 15. $U_o$ vs. $V_w$ for a Smooth Tube at Vacuum Pressure with No Insert

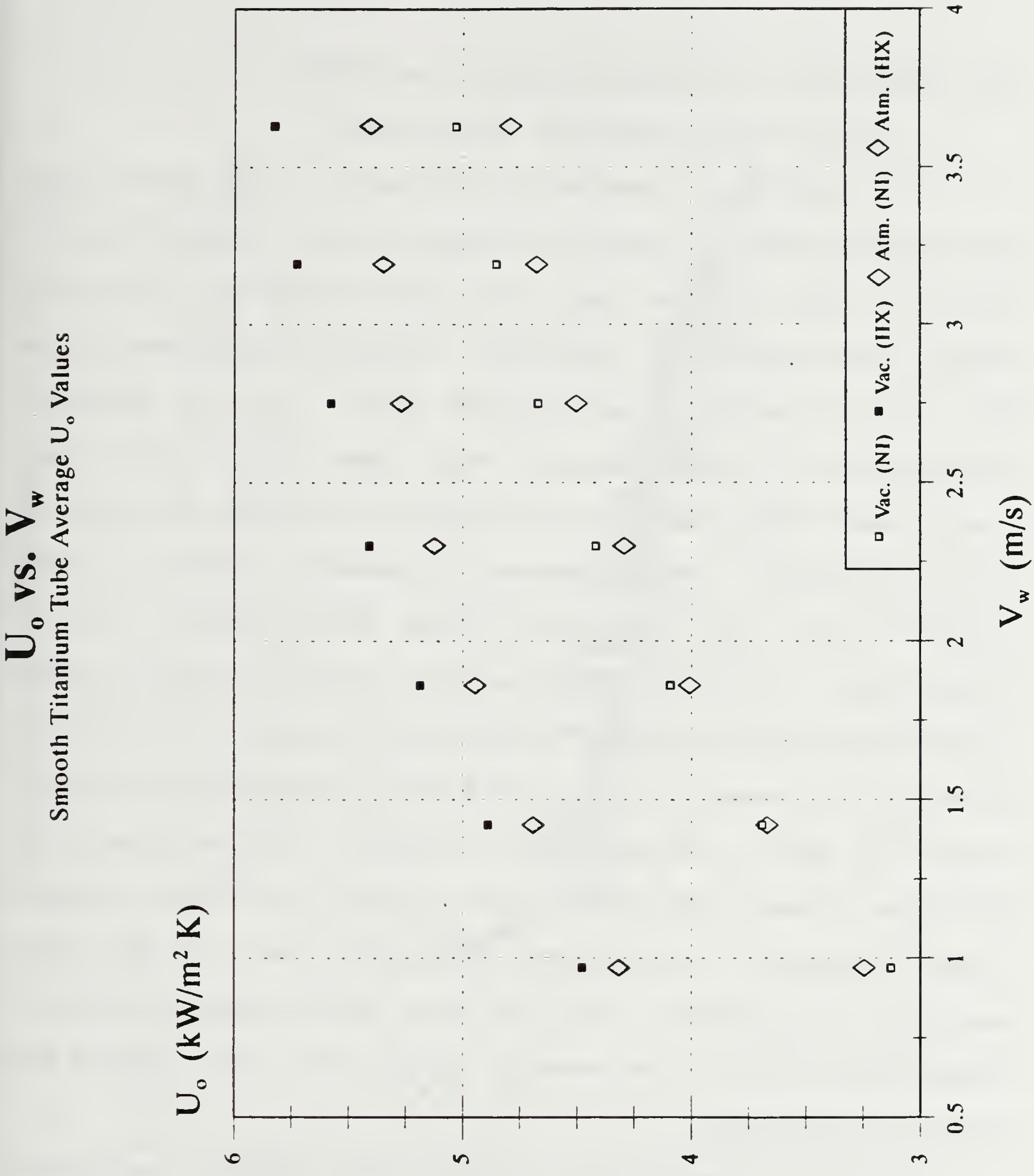


Figure 16. Effect of Vapor Velocity on Smooth Titanium Tubes Average $U_o$ Values

the insert has at the same coolant velocity.

### 2. Outside Heat Transfer Coefficient

The outside heat transfer coefficient is determined using the Nusselt [Ref. 10] equation based on $\Delta T_f$, equation (4.12). Figures 17 and 18 show the outside heat transfer coefficient versus the temperature difference across the condensate film for all the smooth titanium tube data. Several previous researcher's smooth copper tube data have also been reprocessed using the Petukhov-Popov correlation and plotted in the figures. For atmospheric pressure, there is good agreement for all the copper tube data between all the researchers. The titanium tube data, however, tends to fall below the copper tube data, agreeing more closely with Nusselt theory. The reason for the two Nusselt theory lines in each figure is due to the different diameters for the copper and titanium tubes. The vacuum data (Figure 17) shows the same lower values for the titanium tube. The reason for the large scatter is probably due to the much smaller coolant temperature rise in the case of the titanium tube, making the data less accurate.

In order to compare the outside heat transfer coefficient of the smooth tube to each of the enhanced tubes, the Nusselt coefficient, $\alpha$, needs to be determined under similar conditions for each tube. A summary of the results for the data reduction analysis for the leading coefficients ($C_i$)

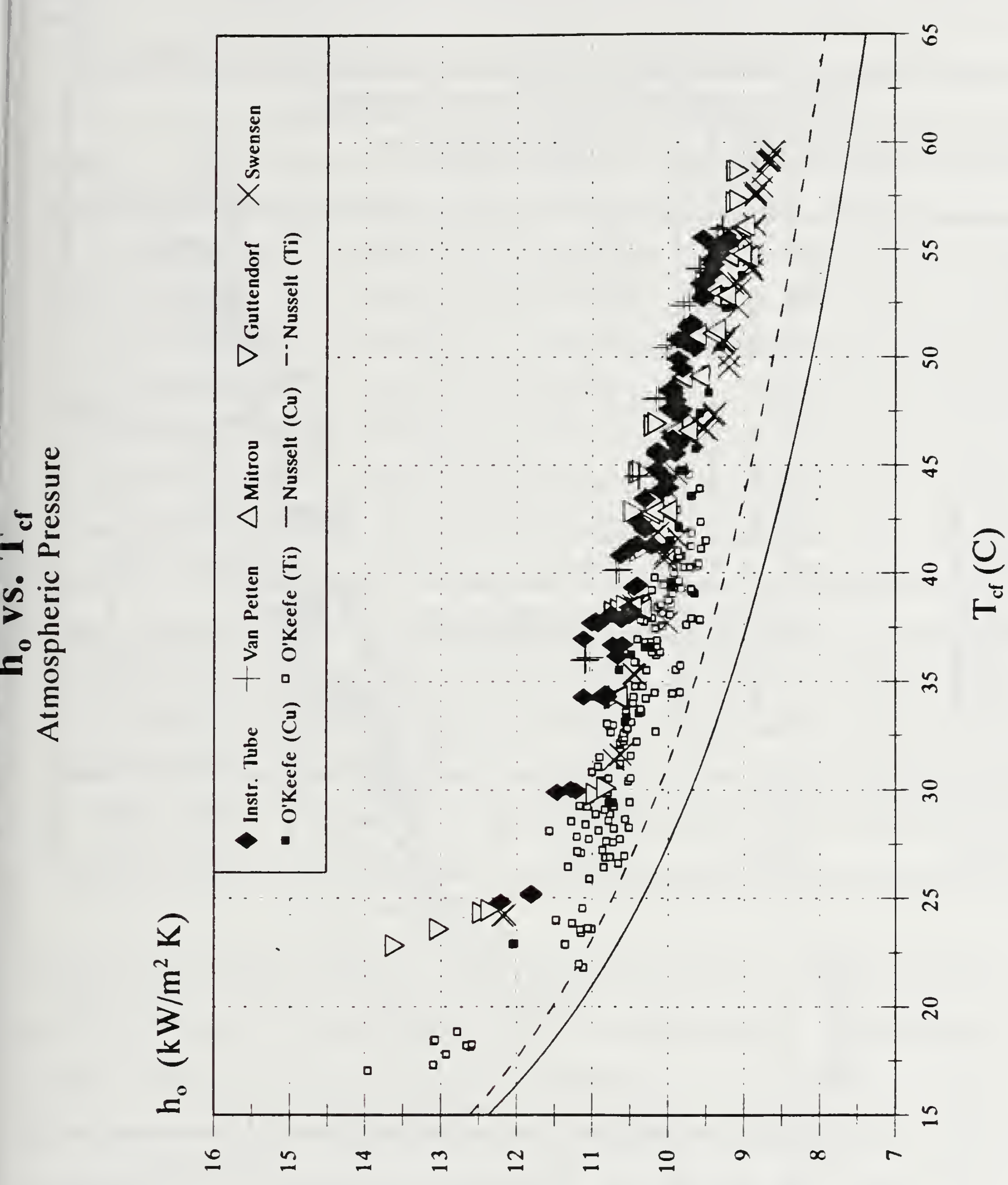


Figure 17. $h_o$ vs. $\Delta T_f$ for Smooth Tubes at Atmospheric Pressure

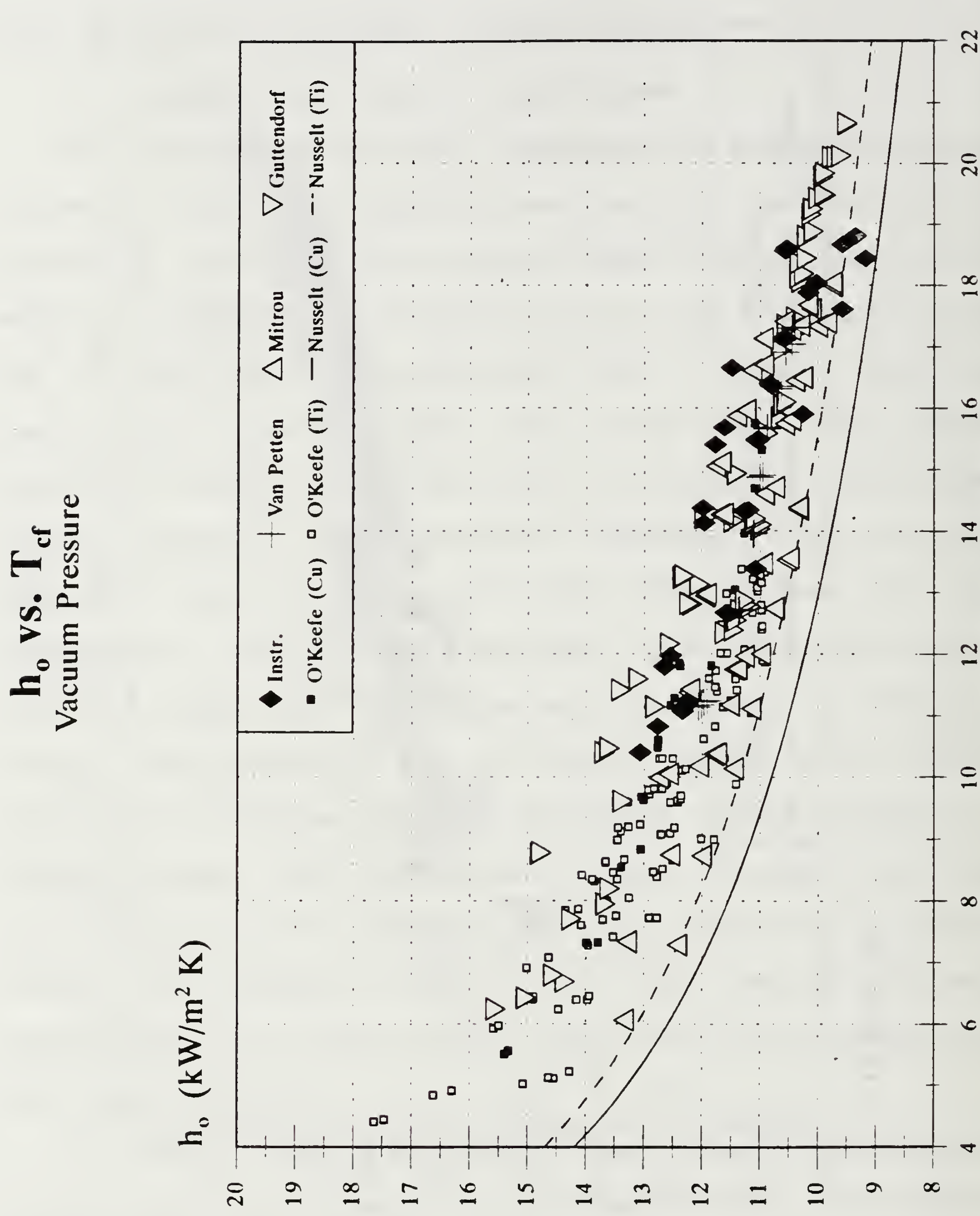


Figure 18. $h_o$ vs. $\Delta T_f$ for a Smooth Tube at Vacuum Pressure

Table II. SMOOTH TITANIUM TUBE WITH A HEATEX INSERT (PRESENT WORK)

| Atmospheric Pressure HEATEX Insert | | | | |
|---|---|---|---|---|
| | Petukhov-Popov | | Sieder-Tate ($Re^{.85}$) | |
| Data Run | $C_i$ | $\alpha$ | $C_i$ | $\alpha$ |
| FONMAHT1 | 2.372 | 0.780 | 0.038 | 0.787 |
| FONMAHT2 | 2.383 | 0.774 | 0.038 | 0.780 |
| FONMAHT3 | 2.392 | 0.755 | 0.038 | 0.761 |
| FONMAHT4 | 2.410 | 0.748 | 0.038 | 0.753 |
| FONMAHT5 | 2.201 | 0.770 | 0.035 | 0.777 |
| FONMAHT6 | 2.541 | 0.776 | 0.040 | 0.781 |
| FONMAHT7 | 2.511 | 0.793 | 0.040 | 0.799 |
| **Atm. Avg.** | **2.401** | **0.776** | **0.038** | **0.777** |
| Vacuum Pressure HEATEX Insert | | | | |
| FONMVHT3 | 2.547 | 0.748 | 0.043 | 0.748 |
| FONMVHT4 | 2.278 | 0.790 | 0.038 | 0.791 |
| FONMVHT5 | 2.422 | 0.763 | 0.041 | 0.763 |
| **Vac. Avg.** | **2.416** | **0.767** | **0.041** | **0.767** |
| **Total Avgs.** | **2.406** | **0.770** | **0.039** | **0.774** |

using the Petukhov-Popov and Sieder-Tate ($Re^{.85}$) correlations, and the Nusselt coefficients ($\alpha$) for the smooth titanium and copper tubes are presented in Tables II through VI. The printouts for all the data runs are given in Appendix D. The researcher initials are as follows: (G)=Guttendorf [Ref. 32], (M)=Mitrou [Ref. 9], (O)=O'Keefe, (S)=Swensen [Ref. 5], and (V)= Van Petten [Ref. 4].

When using the modified Wilson plot technique to reprocess the data, the leading coefficient for the inside heat transfer

Table III. SMOOTH TITANIUM TUBE WITH NO INSERT (PRESENT WORK)

| Atmospheric Pressure No Insert | | | | |
|---|---|---|---|---|
| | Petukhov-Popov | | Sieder-Tate ($Re^{.85}$) | |
| Data Run | $C_i$ | $\alpha$ | $C_i$ | $\alpha$ |
| FONMANT1 | 1.211 | 0.750 | 0.019 | 0.765 |
| FONMANT2 | 1.185 | 0.760 | 0.018 | 0.776 |
| FONMANT3 | 1.169 | 0.765 | 0.018 | 0.777 |
| FONMANT4 | 1.181 | 0.765 | 0.018 | 0.778 |
| FONMANT5 | 1.237 | 0.786 | 0.019 | 0.801 |
| **Avgs.** | **1.197** | **0.765** | **0.018** | **0.779** |
| Vacuum Pressure No Insert | | | | |
| FONMVNT2 | 1.092 | 0.822 | 0.018 | 0.822 |
| FONMVNT3 | 1.078 | 0.788 | 0.018 | 0.789 |
| FONMVNT4 | 1.075 | 0.846 | 0.018 | 0.847 |
| FONMVNT5 | 1.113 | 0.827 | 0.019 | 0.829 |
| **NI Avgs.** | **1.089** | **0.821** | **0.018** | **0.822** |
| **Total Avgs.** | **1.149** | **0.790** | **0.018** | **0.798** |

correlation can either be set with a user supplied value or left to "float", allowing the program to solve for the 'best' value of the coefficient itself as described in Chapter 4. Theoretically, if the leading coefficient is allowed to float, the coefficient should be about the same for all tubes with the same inner diameter. The tables show that the HEATEX inert enhances the inside heat transfer coefficient by a factor of around 2.5. Swensen [Ref. 5] and Micheal et al. [Ref. 33], show that as the vapor velocity across the tube

increases, the value of $\alpha$ increases because of the thinning of the film caused by the vapor shear. In Tables II through VI there is a general trend that the value of $\alpha$ increases between atmospheric ($U_\infty \approx 1.0$ m/s) and vacuum ($U_\infty \approx 2.0$ m/s) runs.

**Table IV.** SMOOTH COPPER TUBE WITH A HEATEX INSERT

| Atmospheric Pressure HEATEX Insert | | | | |
|---|---|---|---|---|
| | Petukhov-Popov | | Sieder-Tate ($Re^{.85}$) | |
| Data Run/Researcher | $C_i$ | $\alpha$ | $C_i$ | $\alpha$ |
| FONMAHC1 (O) | 2.809 | 0.832 | 0.044 | 0.835 |
| FNMAVSH4 (S) | 3.187 | 0.819 | 0.051 | 0.823 |
| FNMAVSH8 (S) | 3.083 | 0.824 | 0.049 | 0.830 |
| FSOMASH3 (S) | 3.031 | 0..818 | 0.048 | 0.826 |
| **Atm. Avgs.** | **3.028** | **0.823** | **0.048** | **0.828** |
| Vacuum Pressure HEATEX Insert | | | | |
| FONMVHC1 (O) | 2.482 | 0.838 | 0.042 | 0.838 |
| **Total Avgs.** | **2.918** | **0.826** | **0.047** | **0.830** |

When the titanium tube is compared to the copper tube, the value of $\alpha$ for the titanium tube is significantly less tha n the $\alpha$ for the copper tube at the same vapor velocity. The value of $\alpha$ could be affected (between titanium and copper) by the difference in temperature profiles at the surface of the tube caused by the different material thermal conductivities. The copper tube will exhibit a much more uniform temperature profile around the tube than the titanium tube. This will affect the properties of the condensate film covering the

Table V. SMOOTH COPPER TUBE WITH A WIRE WRAP INSERT

| Atmospheric Pressure Wire Wrap Insert | | | | |
|---|---|---|---|---|
| | Petukhov-Popov | | Sieder-Tate (Re | |
| Data Run/Researcher | $C_i$ | $\alpha$ | $C_i$ | $\alpha$ |
| SMTHSTA654 (V) | 2.653 | 0.875 | 0.042 | 0.8 |
| S001S1A3 (G) | 2.722 | 0.855 | 0.043 | 0.8 |
| S50A213 (M) | 2.335 | 0.850 | 0.036 | 0.8 |
| S50A220 (M) | 2.272 | 0.834 | 0.035 | 0.8 |
| **Atm. Avgs.** | **2.495** | **0.853** | **0.039** | **0.8** |
| Vacuum Pressure Wire Wrap Insert | | | | |
| M1STV103 (V) | 2.607 | 0.827 | 0.044 | 0.8 |
| S001S1V3 (G) | 2.538 | 0.818 | 0.043 | 0.8 |
| S001S1V4 (G) | 2.575 | 0.823 | 0.043 | 0.8 |
| S001S1V5 (G) | 2.644 | 0.815 | 0.044 | 0.8 |
| S50V181 (M) | 2.102 | 0.856 | 0.035 | 0.8 |
| S50V184 (M) | 2.142 | 0.802 | 0.036 | 0.8 |
| **Vac. Avgs.** | **2.435** | **0.823** | **0.041** | **0.8** |
| **Total Avgs.** | **2.459** | **0.835** | **0.040** | **0.8** |

tube, which in turn affect the values of $\alpha$. Another reason could be the fact that it was much easier to get filmwise condensation on the titanium than on the copper tube, presumably because of the different surface wettablity characteristics of titanium and copper with water. This could lead to differences in the condensate film and even some dropwise condensation in the case of the copper tube.

Table VI. SMOOTH COPPER TUBE WITH NO INSERT

| Atmospheric Pressure No Insert | | | | |
|---|---|---|---|---|
| | Petukhov-Popov | | Sieder-Tate ($Re^{.85}$) | |
| Data Run/Researcher | $C_i$ | $\alpha$ | $C_i$ | $\alpha$ |
| FONMANC1 (O) | 1.265 | 0.816 | 0.019 | 0.828 |
| FSONMASN1 (S) | 1.355 | 0.833 | 0.021 | 0.847 |
| S001S0A2 (G) | 1.347 | 0.858 | 0.021 | 0.875 |
| **Atm. Avgs.** | **1.322** | **0.836** | **0.020** | **0.850** |
| Vacuum Pressure No Insert | | | | |
| FONMVNC1 (O) | 1.085 | 0.866 | 0.018 | 0.867 |
| S001S0V2 (G) | 1.056 | 0.904 | 0.017 | 0.909 |
| S001S0V3 (G) | 1.147 | 0.872 | 0.019 | 0.876 |
| S50V177 (M) | 0.970 | 0.774 | 0.016 | 0.858 |
| **Vac. Avgs.** | **1.064** | **0.854** | **0.018** | **0.857** |
| **Total Avgs.** | **1.175** | **0.846** | **0.019** | **0.841** |

## C. ANALYSIS OF THE WIRE-WRAPPED SMOOTH TUBES

The seven wire-wrapped titanium smooth tubes fabricated for this thesis and two of the wire-wrapped copper tubes used by Mitrou [Ref. 9] were tested under vacuum and atmospheric conditions to find the enhancement compared to a smooth tube for a constant temperature drop across the condensate film. Previous research done in this area has tried to find the optimum relationship between this enhancement and the wire pitch, wire diameter, and the fraction of tube covered by wire.

The overall heat transfer coefficients are similar to the smooth tube curves except that any enhancement due to the wire

can be seen directly on this curve. The same effects caused by the insert and vapor shear (as mentioned previously) also apply to the wire-wrapped tubes. Figure 19 shows the overall heat transfer coefficient for tubes 4-7 at atmospheric pressure with a HEATEX insert. All other $U_o$ data for the rest of the runs are listed in Appendix D.

Figure 20 shows how the outside heat transfer coefficients for tubes 6 and 7 compare with the smooth titanium tube at atmospheric pressure. Tubes 6 and 7 were the only wire-wrapped titanium tubes to show significant enhancement. Both of these tubes were wrapped with a 0.5 mm diameter wire with pitches of 4 mm ($P/D_w$ = 7.92) and 2 mm ($P/D_w$ = 4.02) respectively. Tube 6 showed enhancements between 23% and 30% for vacuum and atmospheric pressure respectively. Figures 21 and 22 show the outside heat transfer coefficient data for tubes 1 through 5. Tube 3 was the only tube to show a degradation in performance as compared to the smooth titanium tube. It had a 1.6 mm wire with a pitch of 3.40 mm ($P/D_w$ = 2.13); the poor performance of this tube is attributed to the effects of condensate retention between the wires on the tube,which were clearly seen. The performance of tubes 1 and 2 were similar to the plain smooth tube. Tubes 4 and 5 showed an enhancement of about 10% over the smooth titanium tube. Tables VII through XI show the results from the data reduction scheme for $C_i$ and $\alpha$ for each data run. The leading coefficients in front of the inside heat transfer correlation

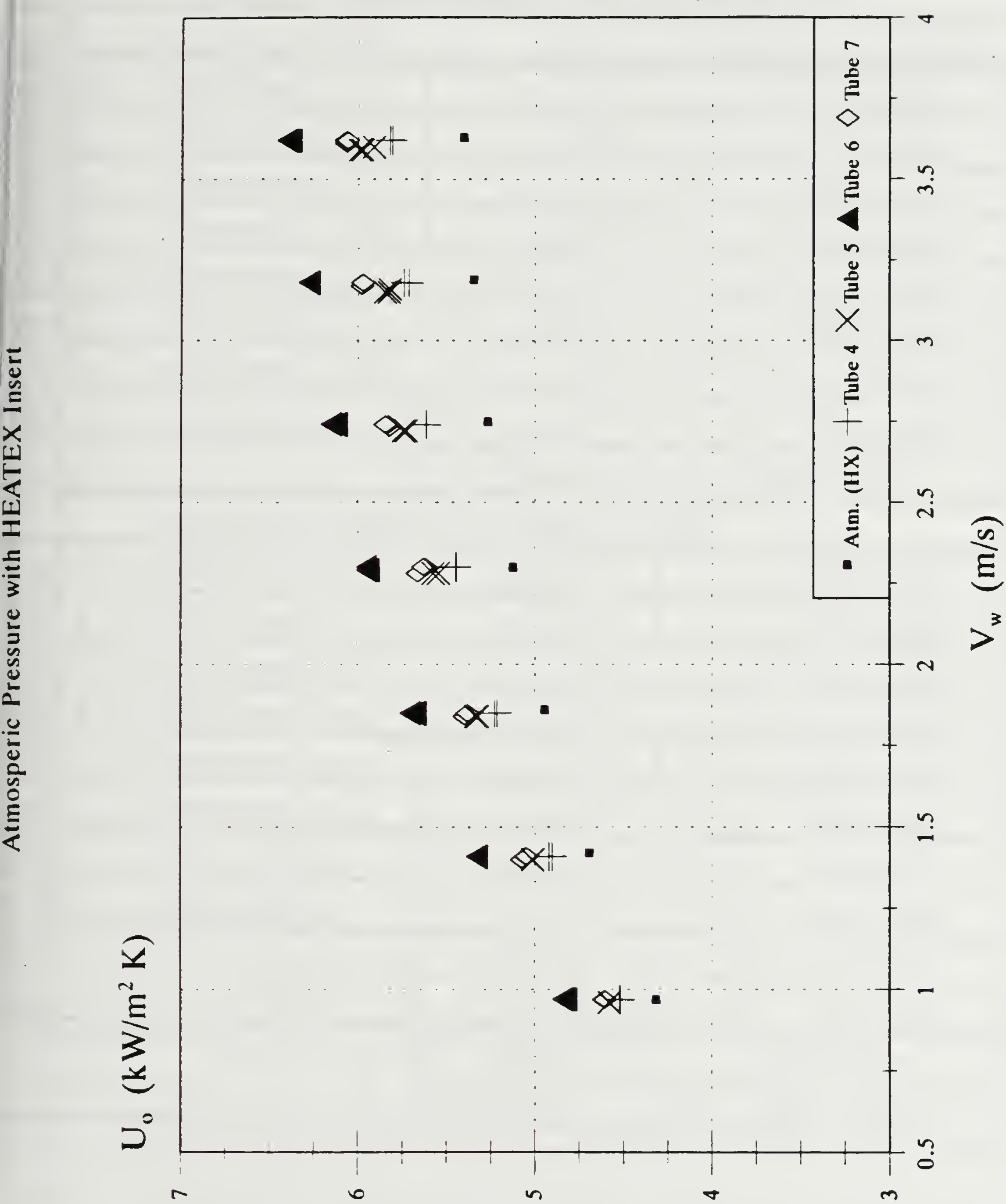


Figure 19. $U_o$ vs $V_w$ for Wire-Wrapped Tubes at Atmospheric Pressure with a Heatex Insert

Table VII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH A HEATEX INSERT

| Data Run / Tube | $C_i$ | $\alpha$ | $E_T$ |
|---|---|---|---|
| Atmospheric Pressure HEATEX Insert | | | |
| FONMAH1T1 (1) | 2.023 | 0.798 | 1.035 |
| FONMAH2T3 (2) | 2.448 | 0.806 | 1.046 |
| FONMAH3T1 (3) | 2.138 | 0.724 | 0.902 |
| FONMAH4T1 (4) | 2.379 | 0.853 | 1.106 |
| FONMAH5T1 (5) | 2.251 | 0.869 | 1.127 |
| FONMAH6T2 (6) | 2.389 | 0.993 | 1.289 |
| FONMAH6T3 (6) | 2.362 | 1.005 | 1.304 |
| FONMAH7T1 (7) | 2.237 | 0.925 | 1.200 |
| **Atm. Avg.** | **2.301** | | |
| Vacuum Pressure HEATEX Insert | | | |
| FONMVH1T1 (1) | 1.892 | 0.802 | 1.045 |
| FONMVH2T1 (2) | 2.005 | 0.797 | 1.038 |
| FONMVH2T2 (2) | 1.948 | 0.787 | 1.026 |
| FONMVH2T3 (2) | 2.240 | 0.766 | 0.999 |
| FONMVH3T2 (3) | 1.866 | 0.618 | 0.714 |
| FONMVH4T1 (4) | 2.081 | 0.821 | 1.071 |
| FONMVH5T1 (5) | 2.014 | 0.842 | 1.097 |
| FONMVH6T1 (6) | 2.160 | 0.950 | 1.238 |
| FONMVH6T2 (6) | 2.214 | 0.946 | 1.233 |
| FONMVH7T2 (7) | 1.956 | 0.855 | 1.115 |
| **Vac. Avg.** | **1.967** | | |
| **Total Avg.** | **2.115** | | |

are consistent with the smooth tube data, as expected.

The copper tubes used by Mitrou [Ref. 9], tubes 68 and 71, were tested to check the repeatability of Mitrou's data. As

Table VIII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH NO INSERT

| Atmospheric Pressure No Insert | | | |
|---|---|---|---|
| Data Run / Tube | $C_i$ | $\alpha$ | $E_T$ |
| FONMAN1T1 (1) | 1.131 | 0.783 | 1.022 |
| FONMAN2T1 (2) | 1.095 | 0.801 | 1.047 |
| FONMAN3T1 (3) | 1.034 | 0.698 | 0.888 |
| FONMAN4T1 (4) | 1.377 | 0.791 | 1.034 |
| FONMAN5T1 (5) | 1.099 | 0.837 | 1.093 |
| FONMAN6T1 (6) | 1.120 | 1.019 | 1.331 |
| FONMAN7T1 (7) | 1.191 | 0.866 | 1.131 |
| **Atm. Avg.** | **1.150** | | |
| Vacuum Pressure No Insert | | | |
| FONMVN1T1 (1) | 1.024 | 0.838 | 1.021 |
| FONMVN2T1 (2) | 0.998 | 0.818 | 0.997 |
| FONMVN3T1 (3) | 0.911 | 0.636 | 0.702 |
| FONMAN4T1 (4) | 1.139 | 0.825 | 1.005 |
| FONMAN5T1 (5) | 0.978 | 0.843 | 1.027 |
| FONMAN6T1 (6) | 1.043 | 1.013 | 1.235 |
| FONMVN7T1 (7) | 0.978 | 0.870 | 1.060 |
| **Vac. Avg.** | **1.010** | | |
| **Total Avg.** | **1.080** | | |

discussed earlier, it was difficult to get good filmwise condensation over the entire tube. The enhancements found were higher than those given by Mitrou's data (reprocessed using the Petukhov-Popov correlation) for tubes 68 and 71; for tube 68, differences of 10% and 17% and for tube 71, differences of 45% and 6% for atmospheric and vacuum pressures

Table IX. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A HEATEX INSERT

| Atmospheric Pressure HEATEX Insert | | | |
|---|---|---|---|
| Data Run | $C_i$ | $\alpha$ | $E_T$ |
| FONMAH68C1 | 2.807 | 1.316 | 1.719 |
| FONMAH71C1 | 3.069 | 1.722 | 2.192 |
| **Atm. Avg.** | 2.938 | | |
| Vacuum Pressure HEATEX Insert | | | |
| FONMVH68C1 | 2.549 | 1.289 | 1.570 |
| FONMVH71C2 | 2.765 | 1.414 | 1.560 |
| **Vac. Avg.** | 2.657 | | |
| **Total Avg.** | 2.797 | | |

respectively. This increase in enhancement could have been due to small patches of dropwise condensation on the surface of the tubes, although it was difficult to see during the experiments due to condensate on the window. Figure 23 shows the comparison of tubes 6 and 71 to a smooth titanium tube. Tubes 6 and 71 have similar pitches and the same wire diameter and should, in theory, give similar values for the outside heat transfer coefficient. However, the enhancement given by the wire-wrapped copper tube (tube 71) is significantly higher (≈35%) than the enhancement given by the wire-wrapped titanium tube (tube 6). This trend tends to reiterate the idea that tube surface wettablity characteristics or tube thermal conductivity may affect the outside heat transfer coefficient.

Table X. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A WIRE WRAP INSERT

| Atmospheric Pressure Wire Wrap Insert | | | |
|---|---|---|---|
| Data Run/Researcher | $C_i$ | $\alpha$ | $E_T$ |
| S68A311 (M) | 2.686 | 1.360 | 1.616 |
| S71A305 (M) | 2.685 | 1.489 | 1.769 |
| S71A314 (M) | 2.692 | 1.473 | 1.749 |
| **Atm. Avg.** | **2.688** | | |
| Vacuum Pressure Wire Wrap Insert | | | |
| S68V283 (M) | 2.452 | 1.182 | 1.401 |
| S68V293 (M) | 2.485 | 1.166 | 1.382 |
| S71V296 (M) | 2.503 | 1.267 | 1.501 |
| **Vac. Avg.** | **2.480** | | |
| **Total Avg.** | **2.584** | | |

In order to see the relationship between the wire pitch, wire diameter and the enhancement, the values of enhancement versus the wire pitch to wire diameter ratio are plotted in Figure 24. Also shown are the newly reprocessed data (using the Petukhov-Popov correlation) from Mitrou [Ref. 9], and the data presented by Sethumadhavan and Rao [Ref. 15]. Even though the experiments were conducted very carefully, the titanium tube data tends to show the most scatter. The data of Sethumadhavan and Rao [Ref. 15] and Mitrou [Ref. 9] demonstrate a maximum enhancement at a $P/D_w$ of about 5. The present data do not show such a clear maximum and tube 6 ($P/D_w$ = 7.96) does not appear to be in line with the data of Sethumadhavan and Rao or Mitrou. Extra experiments were done

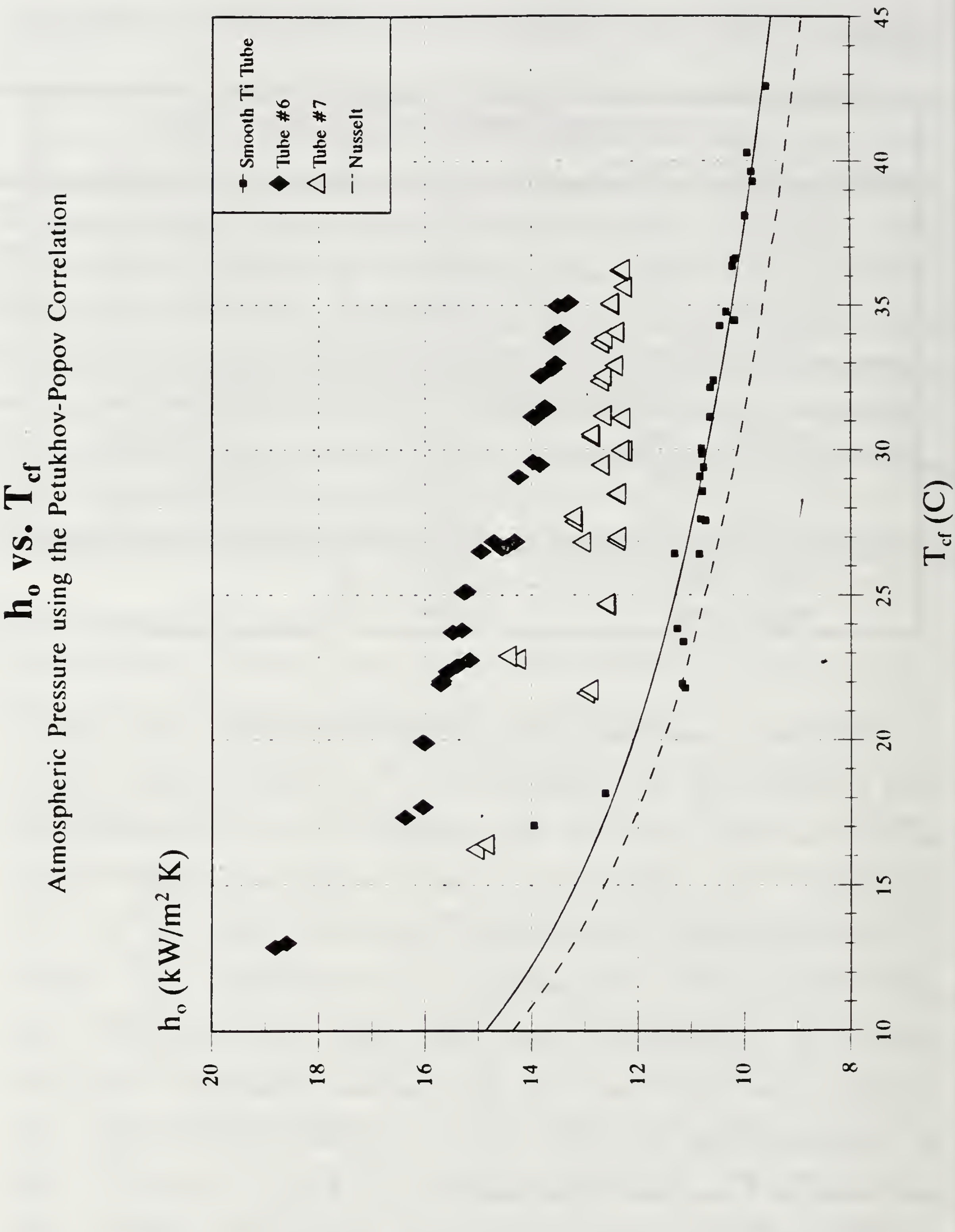


Figure 20. Comparison of the Outside Heat Transfer Coefficients of Tubes 6 and 7 with a Smooth Titanium Tube

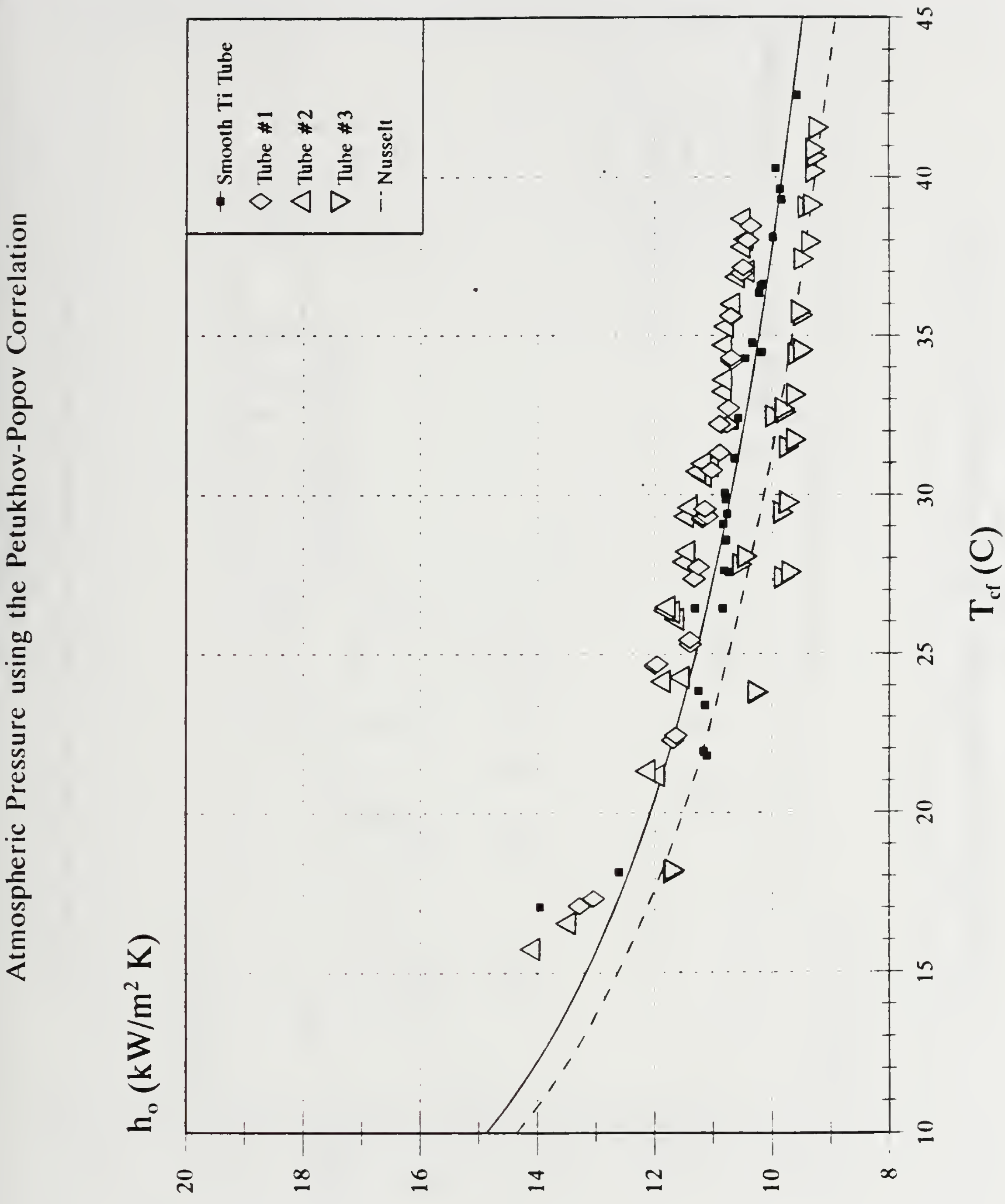


Figure 21. Comparison of the Outside Heat Transfer Coefficients of Tubes 1,2, and 3 to a Smooth Titanium Tube

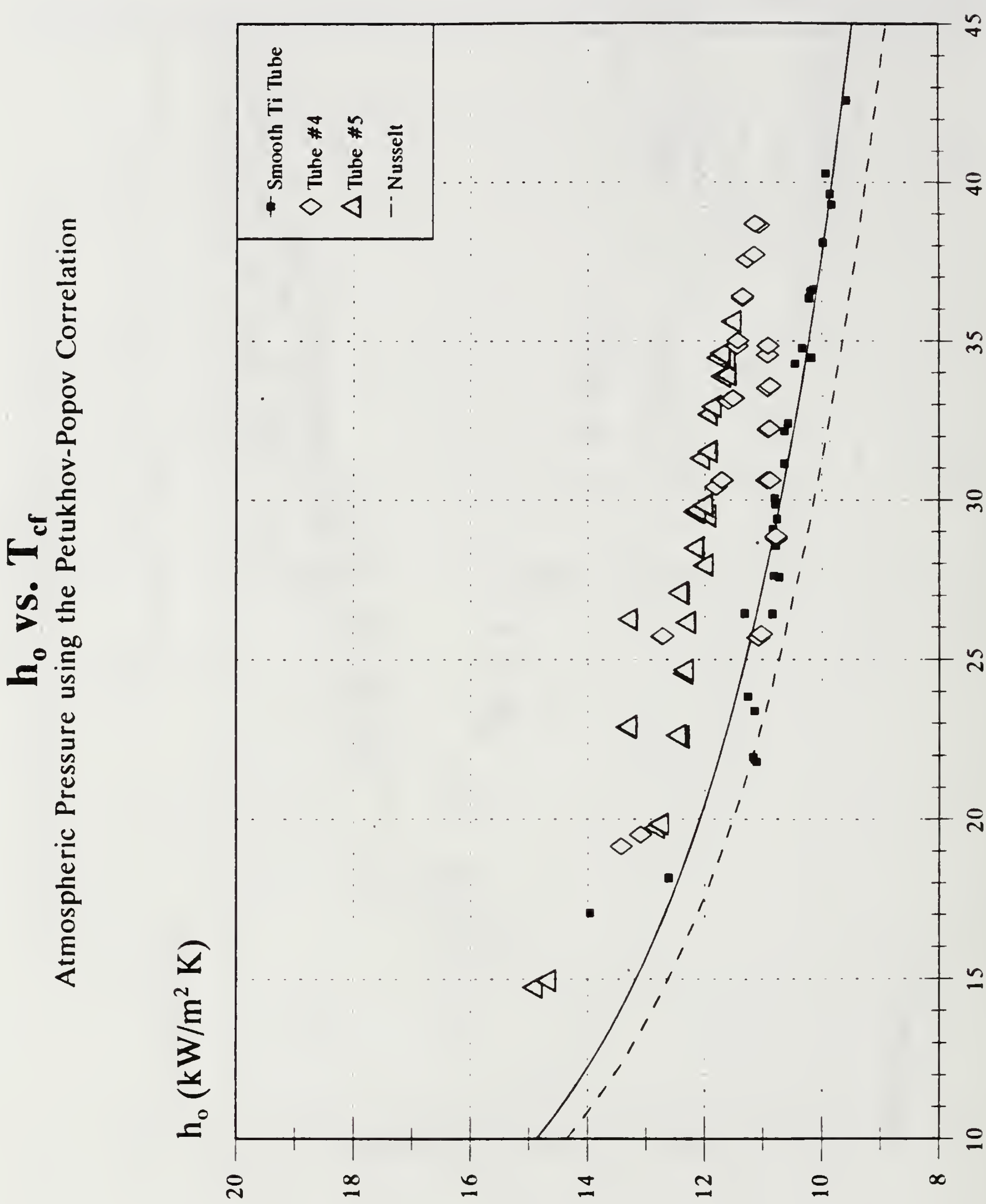


Figure 22. Comparison of the Outside Heat Transfer Coefficients for tubes 4 and 5 to a Smooth Titanium Tube

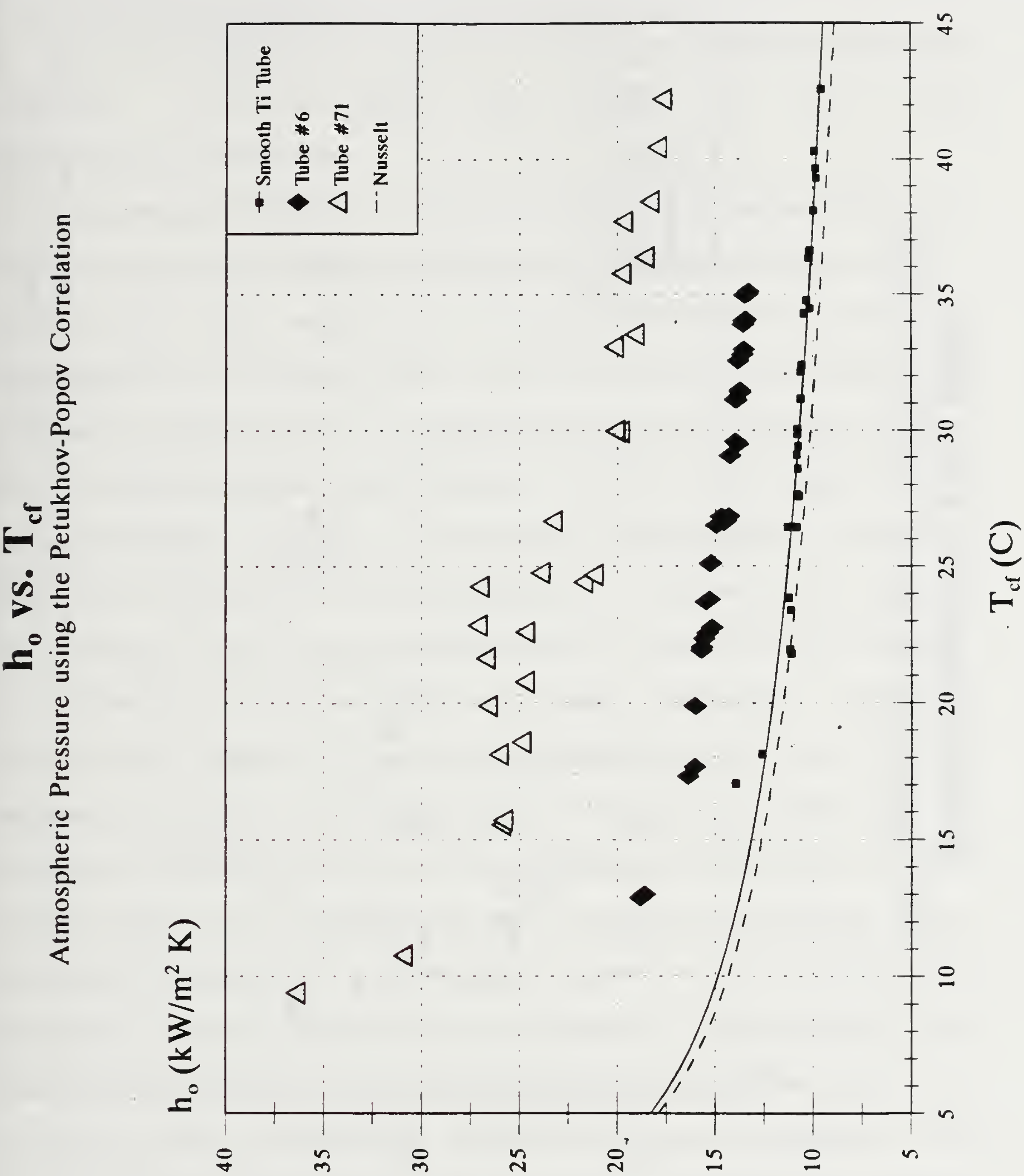


Figure 23. Comparison of the Outside Heat Transfer Coefficients between the Titanium and Copper Tubes

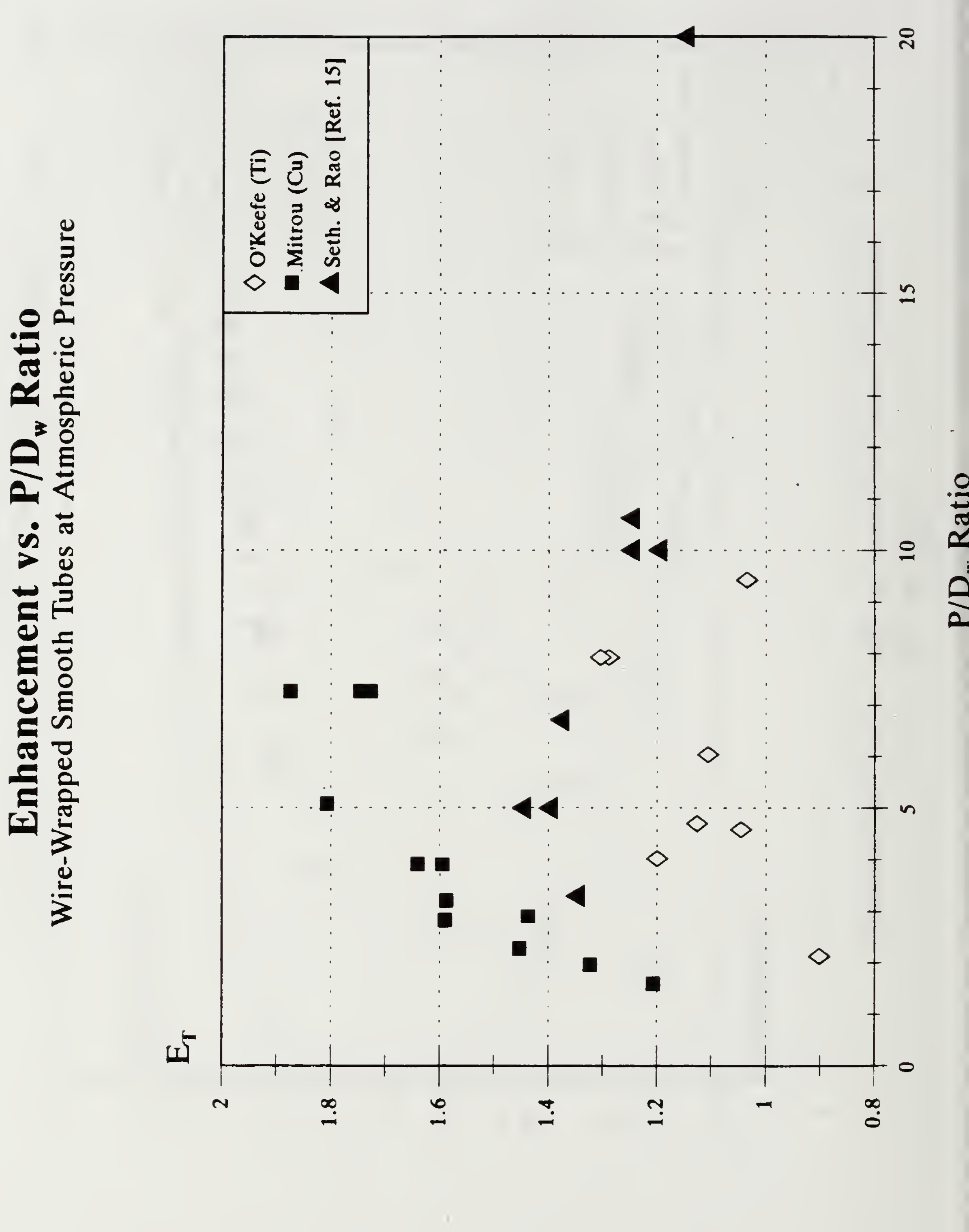


Figure 24. Comparison of the Enhancement vs. $P/D_w$ Ratio of the Data from Mitrou, O'Keefe, and Sethumadhavan & Rao

on tube 6 to check the repeatability with essentially the same results. It would appear that $P/D_w$ is not such a good correlating parameter.

Instead of looking at the $P/D_w$ ratio, the enhancement can also be compared to the percentage of the tube surface that is covered by the wire, F. In the research done by Sethumadhavan and Rao [Ref. 15], the optimal coverage of a tube was found to be 21%. The fractional wire coverage values were determined for the present titanium and copper wire-wrapped tubes. Figure 25 shows the enhancement versus the fraction of the tube covered by wire. The value of 21% for the optimal value of F does not seem to hold for the data in this thesis or for the data of Mitrou. However, this does seem to be a better correlating parameter than $P/D_w$, and the maximum value of the fractional tube coverage seems to lie somewhere between 10% and 30%. The optimal value of F for the copper tube used by Mitrou and the titanium tube appear to be different and there is a definite increase in F as the tube material thermal conductivity increases. Unfortunately, the material of the tube used by Sethumadhavan and Rao [Ref. 15] is not given, although the data would suggest some intermediate conductivity material such as aluminum. Indeed, in another paper by Mehta and Rao [Ref. 22] aluminum tubes were used.

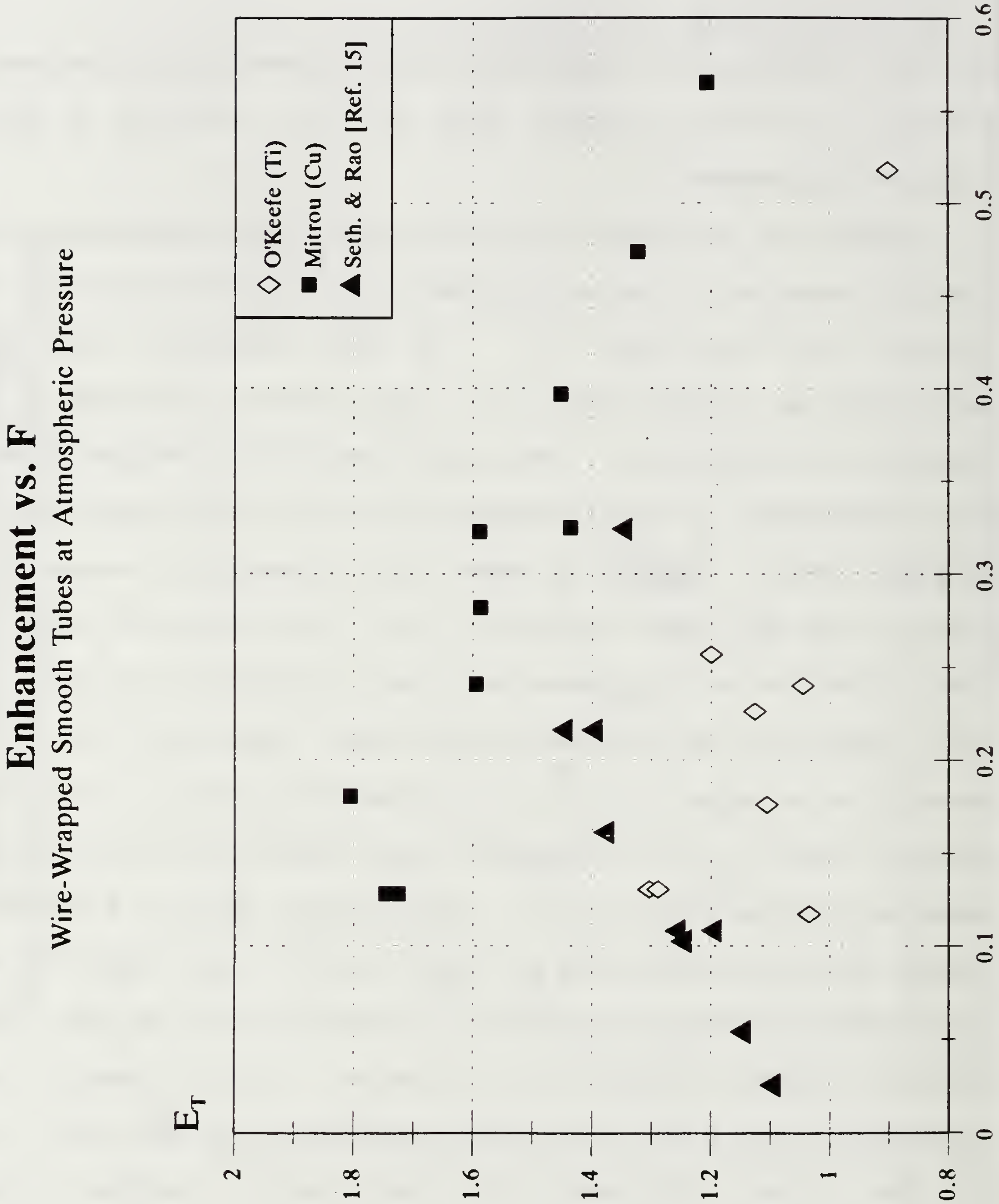


Figure 25. Comparison of the Enhancement vs. F for the data of Mitrou, O'Keefe, and Sethumadhavan & Rao

## D. ANALYSIS OF THE ROPED AND WIRE-WRAPPED ROPED TITANIUM TUBES

Four different roped tubes were tested. One tube was a plain LPD KORODENSE titanium tube that was used to get baseline data for comparing to the plain smooth titanium tube and to the wire-wrapped LPD KORODENSE titanium tubes. The values of the overall heat transfer coefficient are much higher (≈20%) for the LPD KORODENSE tubes when compared to the plain smooth titanium tube. The reason for the increase in the overall heat transfer coefficient is mainly because of the corrugation of the LPD tube on the inside which increases the turbulence of the coolant flow, thereby reducing the inside thermal resistance.

Tables 12 and 13 give the results of the data reduction procedure of all the roped tubes in comparison with the smooth titanium tube. The plain LPD tube consistently gave enhancements of about 20% in the outside heat transfer coefficient, as seen in Figure 26. The wire-wrap was put on the roped tube to try and get an additional enhancement on the outside of the tube. By looking at Tables 12 and 13, the only wire-wrapped LPD tube that showed any enhancement over the plain LPD tube was tube L3 ($D_w$= 0.5 mm). Figure 27 shows the outside heat transfer coefficients for the three wire-wrapped LPD tubes. The wire-wrapped LPD tubes were also checked to see if there was any relation between $P/D_w$ or F and the enhancement over a plain LPD tube ($h_e/h_{LPD}$). Figures 28 and 29

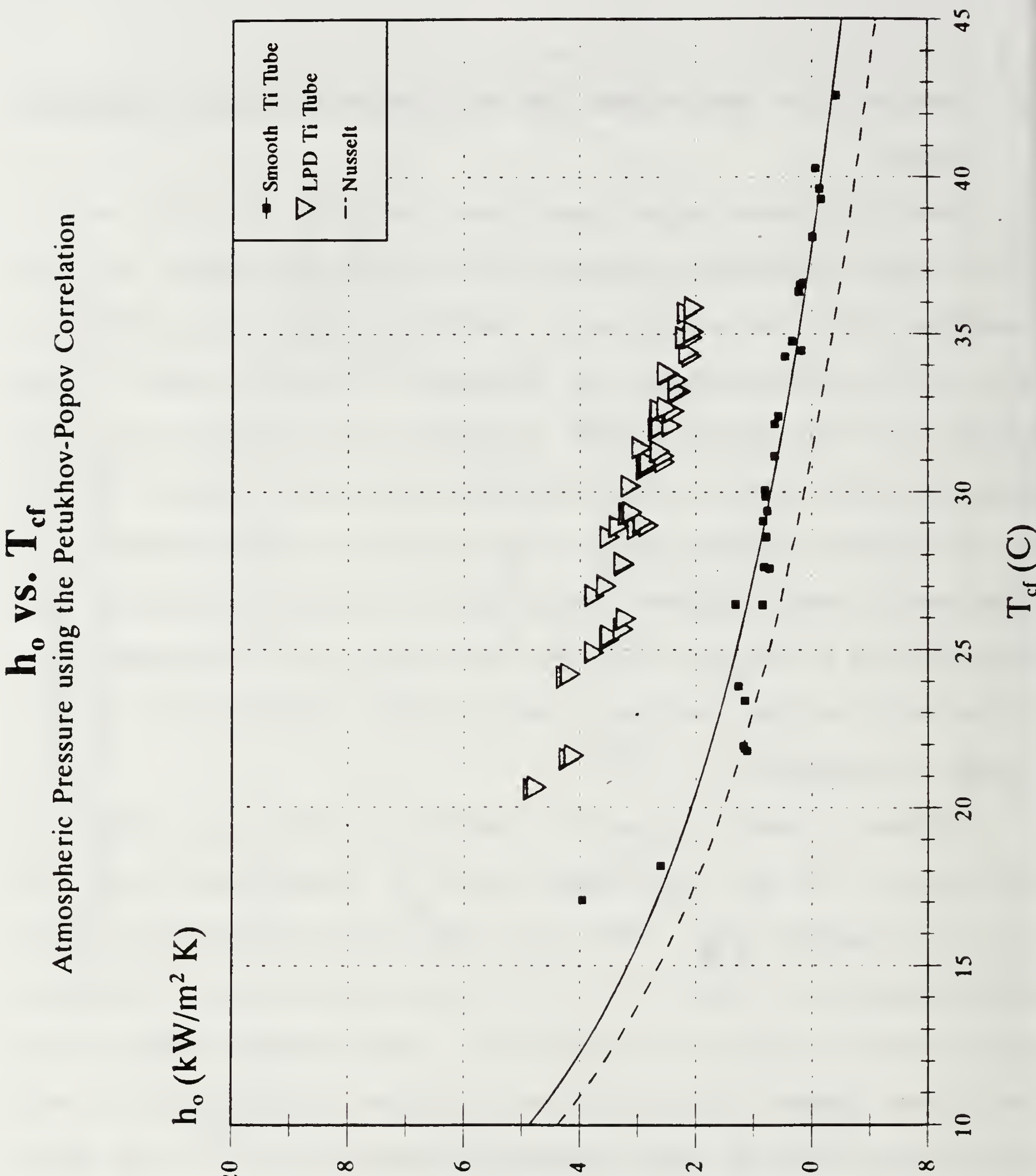


Figure 26. Comparison of the Outside Heat Transfer Coefficients for the plain LPD KORODENSE Tube and the Smooth Titanium Tube

Table XI. LPD KORODENSE TUBES WITH A HEATEX INSERT

| Data Run / Tube | | $C_i$ | $\alpha$ | $E_T$ |
|---|---|---|---|---|
| Atmospheric Pressure HEATEX Insert | | | | |
| FONMAHLT2 | (L) | 2.903 | 0.903 | 1.171 |
| FONMAHLT3 | (L) | 2.892 | 0.916 | 1.188 |
| FONMAHL1T1 | (L1) | 2.667 | 0.890 | 1.154 |
| FONMAHL2T1 | (L2) | 2.639 | 0.909 | 1.179 |
| FONMAHL3T1 | (L3) | 2.835 | 0.968 | 1.256 |
| **Atm. Avg.** | | **2.787** | | |
| Vacuum Pressure HEATEX Insert | | | | |
| FONMVHLT1 | (L) | 2.717 | 0.945 | 1.232 |
| FONMVHLT2 | (L) | 2.669 | 0.950 | 1.238 |
| FONMVHL1T2 | (L1) | 2.317 | 0.880 | 1.147 |
| FONMVHL2T3 | (L2) | 2.426 | 0.890 | 1.161 |
| FONMVHL3T2 | (L3) | 2.609 | 0.995 | 1.297 |
| **Vac. Avg.** | | **2.548** | | |
| **Total Avg.** | | **2.667** | | |

show respectively the relationship between $P/D_w$ and F to the enhancement over the plain LPD tube. Since the pitch here is fixed, Figure 28 indicates that there may be further enhancement possible if a smaller diameter wire is used. Figure 29 suggests there may be an optimal fractional coverage of the tube between 0 and 0.07. Based on the results from the wire-wrapped smooth titanium tubes, the maximum enhancement seen was about 30%; for the plain LPD tube over the plain smooth titanium tube the enhancement was about 20%.

Table XII. LPD KORODENSE TUBES WITH NO INSERT

| Atmospheric Pressure No Insert | | | |
|---|---|---|---|
| Data Run / Tube | $C_i$ | $\alpha$ | $E_T$ |
| FONMANLT2 (L) | 2.056 | 0.919 | 1.201 |
| FONMANLT3 (L) | 1.993 | 0.941 | 1.230 |
| FONMANL1T1 (L1) | 2.036 | 0.869 | 1.135 |
| FONMANL2T1 (L2) | 2.057 | 0.890 | 1.163 |
| FONMANL3T1 (L3) | 2.202 | 0.933 | 1.219 |
| **Atm. Avg.** | **2.069** | | |
| Vacuum Pressure No Insert | | | |
| FONMVNLT2 (L) | 1.869 | 0.953 | 1.161 |
| FONMVNLT3 (L) | 1.862 | 0.956 | 1.165 |
| FONMVNL1T2 (L1) | 1.784 | 0.855 | 1.041 |
| FONMVNL2T3 (L2) | 1.839 | 0.869 | 1.059 |
| FONMVNL3T2 (L3) | 2.041 | 0.942 | 1.148 |
| **Vac. Avg.** | **1.879** | | |
| **Total Avg.** | **1.974** | | |

Therefore, the maximum additional enhancement expected from wire-wrapping the LPD tube with a smaller diameter wire would be about 10%.

One reason the larger diameter wires did not improve the outside enhancement of the LPD tubes is that there was more condensate retained between the wires than with the plain LPD tube. This additional condensate causes a thicker condensate film across the lower portion of the tube, resulting in less overall heat transfer. The smallest wire (0.5 mm) fitted into

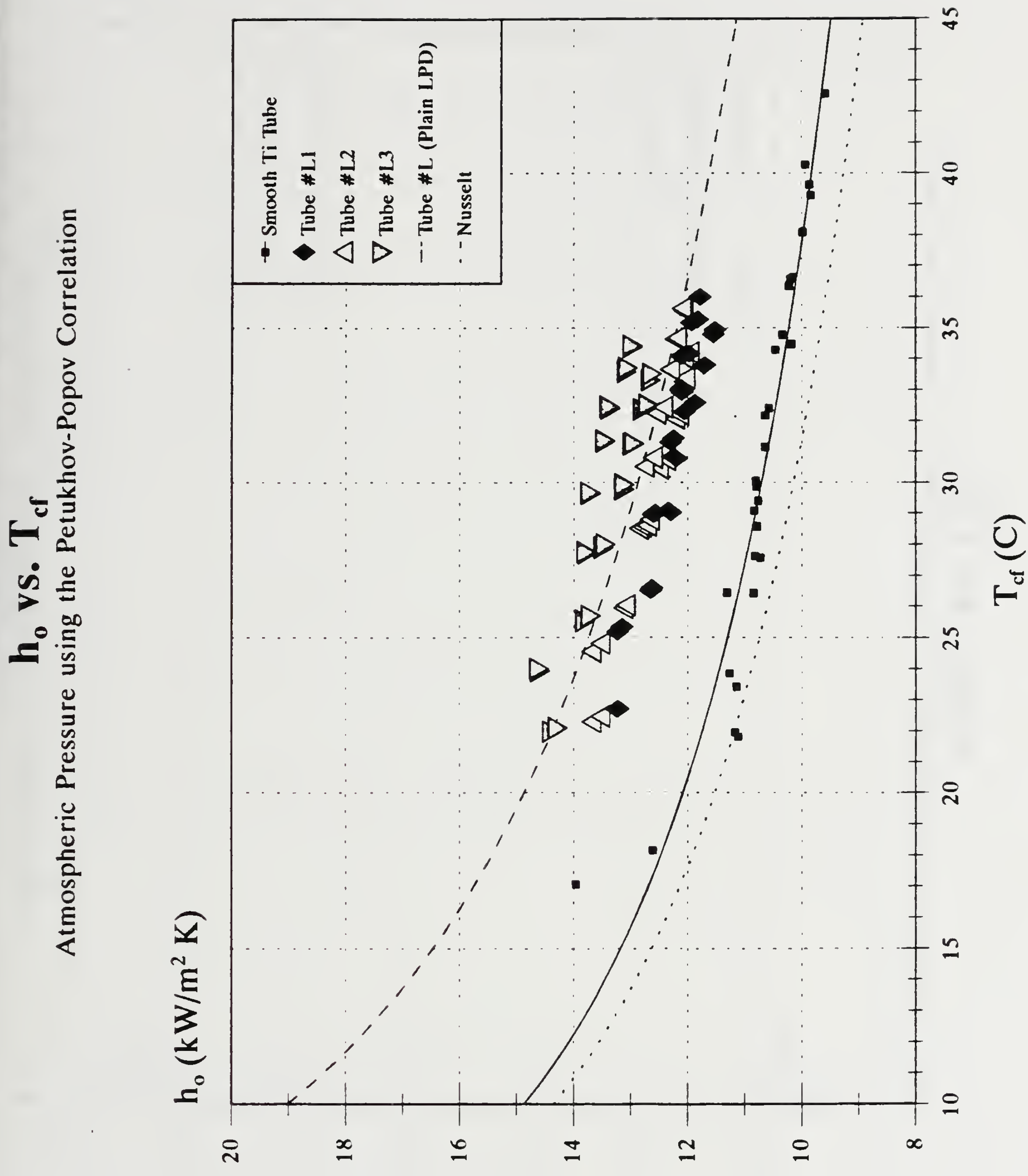


Figure 27. Comparison of the Outside Heat Transfer Coefficient for the Wire-Wrapped LPD KORODENSE Titanium Tubes and the Smooth Titanium Tube

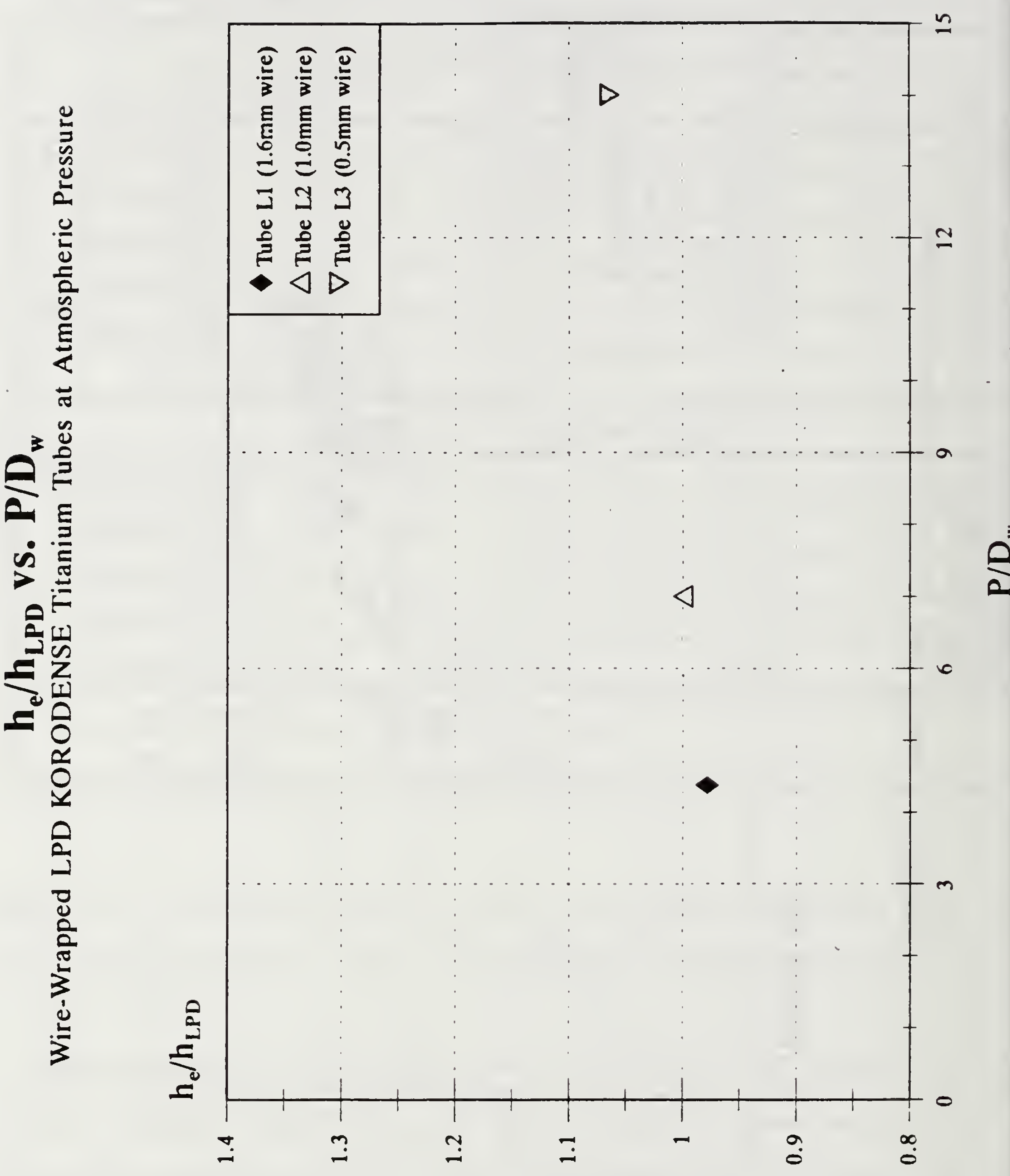


Figure 28. Comparison of $h_e/h_{os}$ vs. $P/D_w$ Ratio for the Wire-Wrapped LPD KORODENSE Tubes

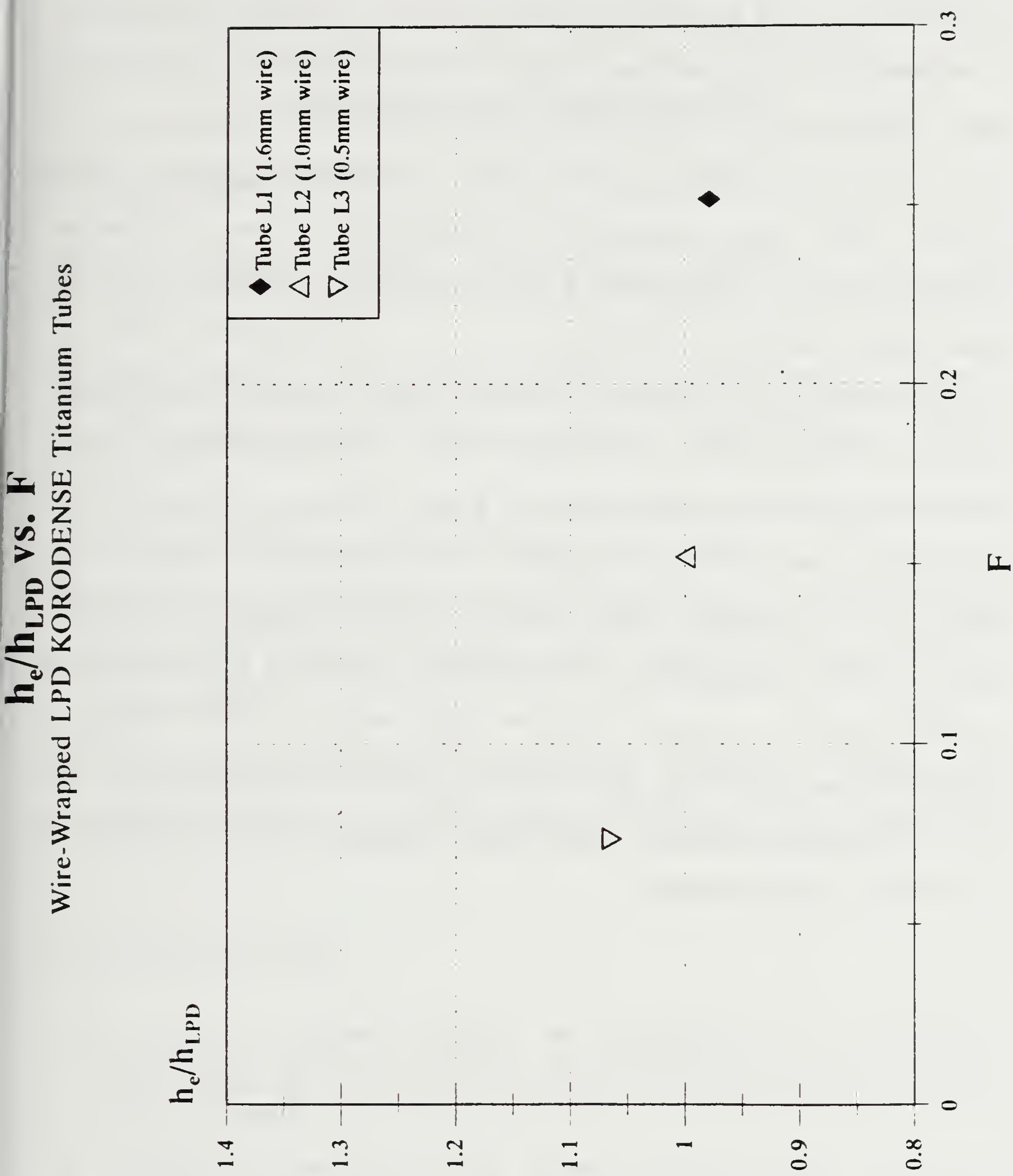


Figure 29. Comparison of $h_e/h_{LPD}$ vs. F for the Wire-Wrapped LPD KORODENSE tubes

the groove of the roped tube more closely, so that the amount of condensate retained was about the same as for a plain LPD tube. Since there was no additional condensate retention, the wire was better able to draw the condensate film to the groove. The larger pressure differential leads to greater thinning of the condensate film and thus a reduction in the vapor side thermal resistance.

In summary, the maximum enhancement in the outside heat transfer coefficient realized for a wire-wrapped smooth titanium tube was ≈30% with a $P/D_w = 7.96$. A plain LPD KORODENSE tube showed consistent enhancements of ≈20% in the outside heat transfer coefficient when compared to a smooth tube. There only seems to be a minimal gain in wire-wrapping an LPD tube to further improve the outside heat transfer coefficient. However, one benefit to wire-wrapping an LPD tube would be to reduce the effects of condensate inundation in a bundle arrangement.

# CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS

1. The Petukhov-Popov inside heat transfer coefficient correlation can be used to give accurate results in this test apparatus.

2. Enhancements in the outside heat transfer coefficient of up to 30% were obtained using a wire-wrapped titanium tube, when compared to the smooth titanium tube. ($P/D_w$ = 7.92)

3. An optimal value of the fractional wire coverage of the tube of between 10% and 30% was found.

4. For an LPD KORODENSE titanium roped tube, an enhancement in the outside heat transfer coefficient of up to 20% over the smooth titanium tube was obtained. Using a wire-wrap on the LPD KORODENSE tube showed little further enhancement.

5. The surface wettability characteristics and perhaps the thermal conductivity of the tube material seems to have an influence on the outside heat transfer coefficient and possibly the optimal fractional wire coverage.

## B. RECOMMENDATIONS

1. A set of tubes should be fabricated of different materials with fractional wire coverage of the tube in the range of 0.1 to 0.3, using different wire diameters and pitches.

2. Determine the effect of vapor velocity and inundation effects on the titanium wire-wrapped tubes. Use the Fujii [Ref. 12] correlation for the outside heat transfer coefficient when reprocessing the data.

3. Fabricate several more wire-wrapped LPD KORODENSE tubes using thinner wire diameters (0.1 mm, 0.2 mm, and 0.3 mm). To determine if there is a significant increase in

the enhancement of the outside heat transfer coefficient and an optimal value for the fractional wire coverage of the tube.

4. Reprocess the data sets using all the data for a given configuration (i.e. pressure, insert used, etc...) to determine more accurate values of $C_i$ and $\alpha$.

5. Conduct bundle tests to see if condensate inundation is reduced with wire-wrapped smooth and roped tubes.

# APPENDIX A. SYSTEM CORRECTIONS

## A. FRICTIONAL TEMPERATURE CORRECTIONS

When the coolant flows through the tube there is a temperature rise in the bulk fluid due to frictional heating. The amount of heating is dependent on the fluid velocity and the inside geometry of the tube. The actual temperature is small, but it can have a significant effect on the calculation for the overall heat transfer coefficient. The titanium tubes had a smaller temperature rise across the tube than the copper tubes, so the effect of the frictional heating is much greater. Measurements were made for the smooth titanium tube on August 7, 1992 and August 14, 1992 for the LPD KORODENSE titanium tube. The data is plotted in Figures A.1 and A.2. Runs were conducted with and without the HEATEX insert. The data was curve fitted to a third order polynomial as shown in Table A.1.

Table A.1 FRICTION TEMPERATURE RISE EQUATIONS

| Tube/Insert Type | Polynomial Equation |
|---|---|
| Smooth/None | $T_{rise} = -8.843\times10^{-5}V^3 + 1.799\times10^{-3}V^2 - 7.526\times10^{-4}V - 4.617\times10^{-5}$ |
| Smooth/HEATEX | $T_{rise} = -3.305\times10^{-5}V^3 + 2.122\times10^{-3}V^2 + 9.737\times10^{-4}V + 2.091\times10^{-4}$ |
| LPD/None | $T_{rise} = 4.133\times10^{-5}V^3 + 6.013\times10^{-4}V^2 + 1.880\times10^{-3}V - 3.386\times10^{-4}$ |
| LPD/HEATEX | $T_{rise} = -2.781\times10^{-5}V^3 + 1.893\times10^{-3}V^2 + 9.202\times10^{-4}V + 2.089\times10^{-4}$ |

where: $T_{rise}$ = temperature rise (°K)
$V$ = fluid velocity (m/s)

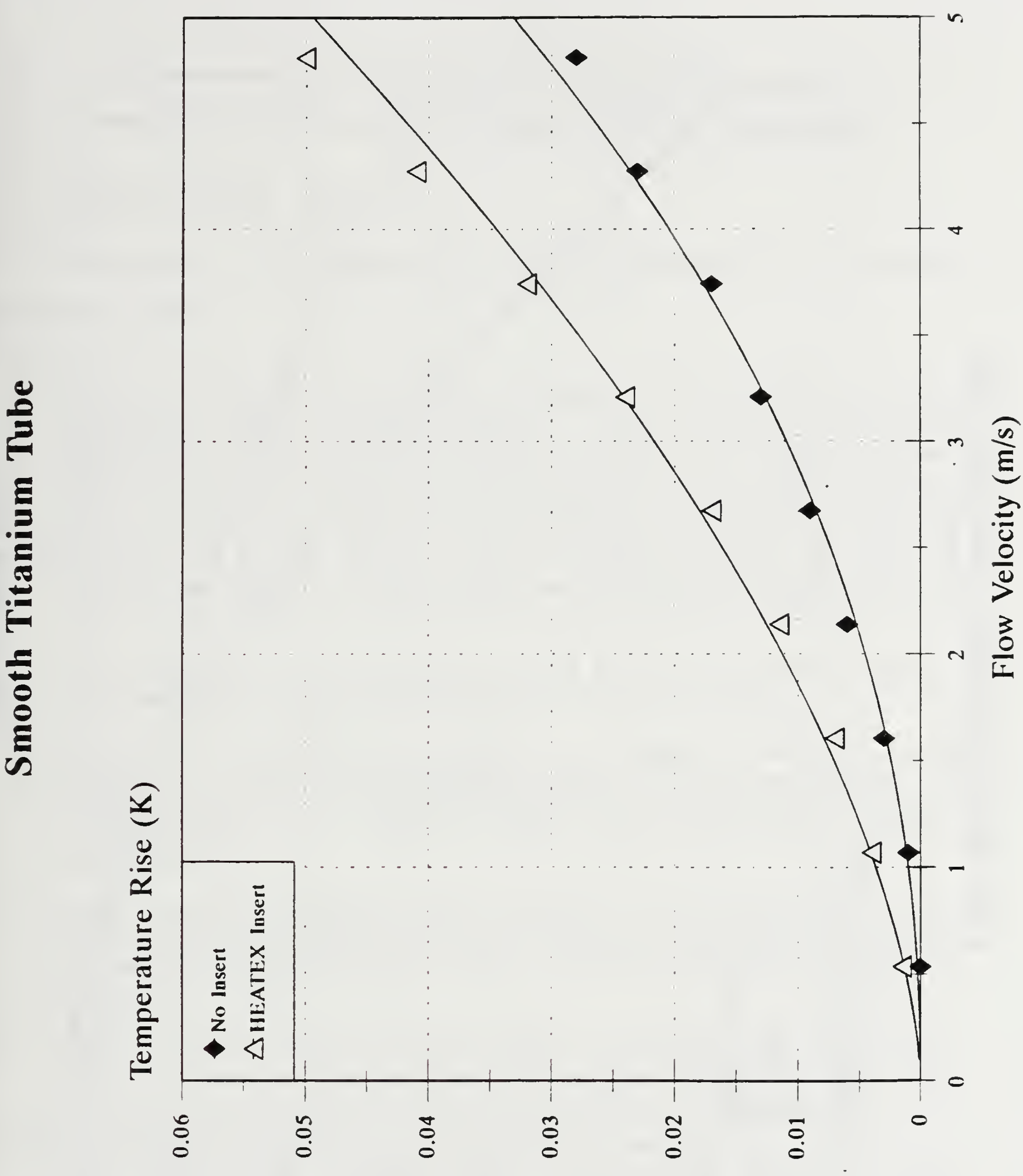


Figure A.1 Frictional Temperature Rise Curves for the Smooth Titanium Tube with a HEATEX Insert and No Insert.

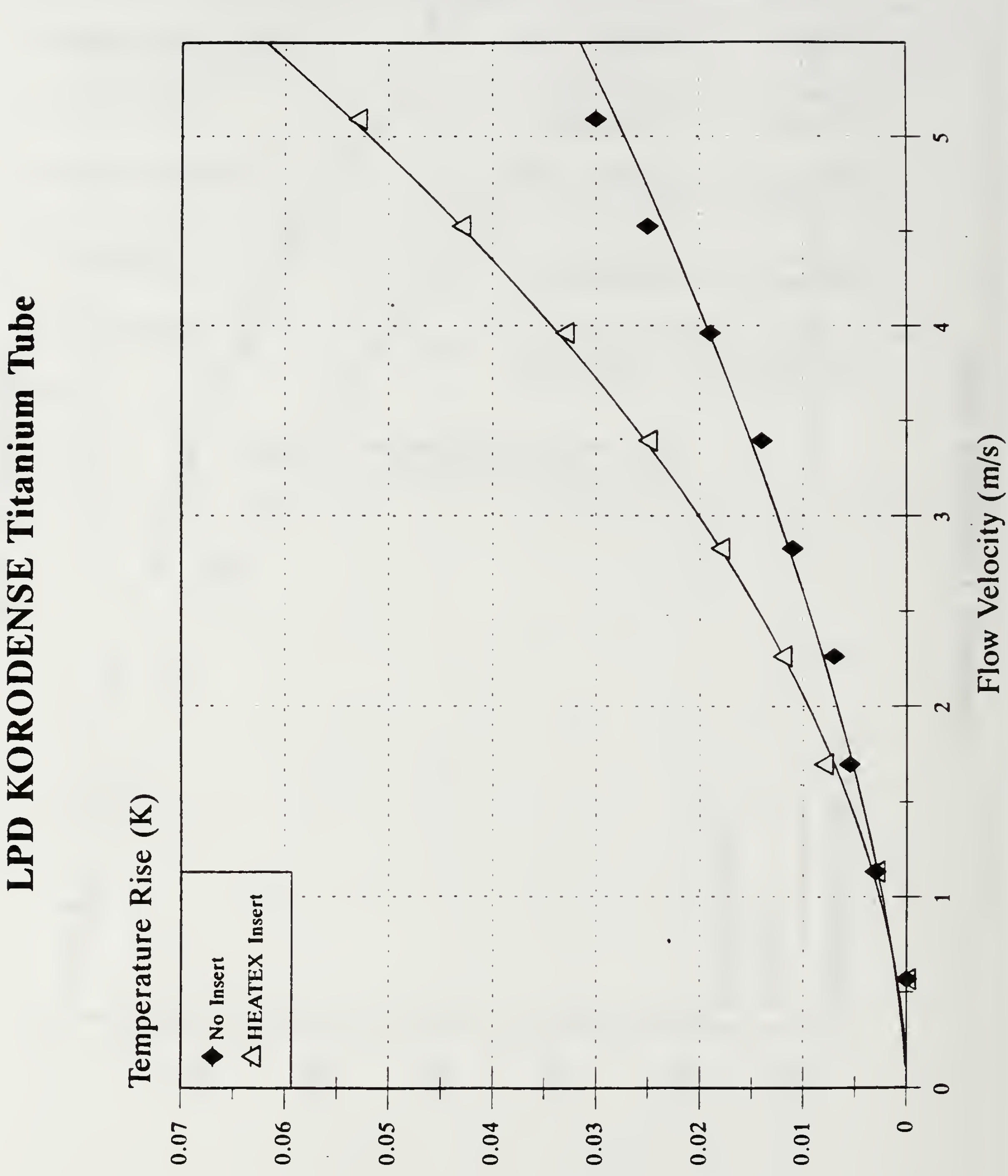


Figure A.2 Frictional Temperature Rise Curves for the LPD KORODENSE Titanium Tube with a HEATEX Insert and No Insert

# APPENDIX B. SYSTEM STARTUP AND SHUTDOWN PROCEDURES

## A. SYSTEM STARTUP PROCEDURE

When preparing the system for taking data the following should be done:

1. Ensure the boiler section of the system is filled with distilled water, approximately 4 to 6 inches above the heaters. To fill the boiler a hose is attached between the distilled water tank and the boiler fill/drain valve. Ensure the vent valve by the auxiliary condenser is open prior to gravity filling the boiler. The boiler can be drained by ensuring the hose is removed from the boiler fill/drain valve. Then open the fill/drain valve and let the water drain to the bilge area below the boiler.

2. If the boiler has the appropriate water level then ensure the vent valve and fill/drain valve are shut.

3. Energize the data acquisition system, computer, and printer. Load the software program DRPOK and check for proper operation. Before starting any heaters check all thermocouples to ensure they are reading ambient temperature.

4. Open the fill valve to the coolant sump tank and set the flow rate such that the drain box does not overflow. (the valve is located to the left of the boiler heater control panel.)

5. Turn on the cooling water supply pumps and set the flow rate between 40% to 60% and check for leaks in the test section. Secure the flow and coolant supply pumps.

6. Open the valve supplying water to the auxiliary condenser unit and adjust the flow rate to at least 30% and check for leaks in the system. When the leak check is complete reset the flow rate as desired but at least greater than 10%.

7. CAUTION: prior to energizing any heaters ensure that the system is under a vacuum. To draw a vacuum on the system, ensure the drain valve on the plexiglas container

is shut. Check that there is flow to the sump tank, then energize the vacuum pump and open the suction valve located on the side of the auxiliary condenser. Allow the vacuum pump to run until the system pressure is below 3 psia, then shut the suction valve and secure the vacuum pump.

8. The heaters may be energized if the system is confirmed to be under vacuum conditions. To energize the heaters three switches must be placed in the "ON" position. The first switch is located on power panel p5, switch #3, in the main hallway adjacent to H-106. The second switch, the heater load bank circuit breaker, is located on the left side of the boiler heater control panel. The final switch, the condensing rig boiler power switch, is located on the front of the boiler heater control panel. When the heaters are energized, the power level should be set at 50 volts (40 volts if the system is below 2 psia to limit the vibrational shock to the system from vapor bubble formation). As the system warms up, the power can be increased at 10 volt increments until the desired setting is reached.

9. As the system warms up and the system pressure rises above 4 psia, then the non-condensible gases need to be flushed out of the system by drawing a vacuum on the system following step 7. To ensure the non-condensible gases collect at the base of the auxiliary condenser, coolant flow should remain secured and the flow rate to the auxiliary condenser adjusted until all the gases have been purged from the system. When the auxiliary condenser is warm to the touch everywhere, this is an indication that steam is filling the entire condenser and little or no non-condensible gases remain. To initially purge the system of non-condensible gases may take between 15 and 30 minutes. The process should be done every few hours if extended operation of the system is required.

10. To ensure that filmwise condensation is established on the tube being tested, the following should be done:

    a. Allow the apparatus to warm up to a vapor temperature of at least 3800 microvolts.

    b. Raise the auxiliary coolant flow rate to 50% or 60% to cool the vapor temperature to approximately 3200 microvolts.

c. Secure coolant flow to the auxiliary condenser and allow the vapor temperature to rise to about 3700 microvolts. This forms a steam blanket over the tube.

d. Initiate coolant flow of 80% in the auxiliary condenser.

e. Adjust the coolant flowrate in the auxiliary condenser to maintain the desired temperature and pressure for the system.

11. Run the software program DRPOK by pressing the "run" key on the keyboard. The program will prompt you with questions for the necessary information it needs as follows:

- Select option ... Enter 0 for taking new data
- Select fluid ... Enter 0 for water
- Enter input mode ... Enter 0 for new data
- Enter month, date, time ... when finished press enter
- Select $C_i$ ... 0 to find $C_i$ and 1 to use the program value
- Give a name for the raw data set ... enter the name
- Enter the geometry code ... select plain or finned
- Enter the insert type used... select the appropriate value
- Enter the tube type ... select the appropriate value
- Select the tube enhancement used ... select the appropriate value
- Select the tube material ... enter 0 for copper
- Select the tube diameter ... enter 1 for medium
- Enter the pressure condition ... 0 vacuum, 1 atmospheric
- Select the inside correlation ... 0 Sieder-Tate, 2 Petukhov-Popov
- Select the outside theory for analysis ... 0 Nusselt or 1 Fujii

- Select the measurement device ... 1 Quartz thermometer
- Select the output ... 0 short, 1 long
- Like to check NG concentration ... 1 yes, 2 no
- Enter flowmeter reading (%) ... enter a 2 digit number
- Connect voltage line ... flip up voltage line toggle switch on and press enter
- Disconnect voltage line ... flip voltage line toggle off and press enter
- Enter pressure gage reading ... input reading from Heise gage and press enter
- Change TCOOL rise? ... 1 yes, 2 no
- OK to store this point? ... 1 yes, 2 no
- Will there be another run? ... 1 yes, 0 no; if yes it returns to the step Like to check NG concentration for following runs

12. Prior to continuing past the question "Enter the flowmeter reading" ensure the system has been operating at steady-state conditions for at least 30 minutes.

13. **<u>WARNING</u>**: carefully monitor vapor pressure during warmup, especially around atmospheric pressure, to ensure an overpressure condition does not occur.

14. Vacuum runs are conducted at a heater setting of 90 volts and 1980 ± 10 microvolts on channel 40. This corresponds to $T_{sat} \approx 48^\circ C$, and a vapor velocity of ≈2 m/s.

15. Atmospheric runs are performed at a heater setting of 175 volts and 4280 ± 10 microvolts on channel 40. This corresponds to $T_{sat} \approx 100^\circ C$, and a vapor velocity of ≈1 m/s.

16. The viewing window can be cleared of condensation by using heated air from a blow dryer on the glass. **<u>CAUTION</u>**: be careful not to overheat and crack the glass.

17. When taking readings always double check the flowmeter reading prior to accepting any data point. Also, always conduct vacuum runs prior to atmospheric runs because it takes too long for the system to cool down to the vacuum operating temperatures. When trying to conduct both atmospheric and vacuum runs in the same day.

## B. SYSTEM SHUTDOWN PROCEDURES

When completed taking data, the system should be secured with the following procedure:

1. Secure power to the heating elements. Turn off the switches on the boiler heater control panel.

2. Secure coolant flow in the auxiliary condenser. If the system is to remain at vacuum pressure until the next data run, then the auxiliary condenser can be used in assisting to cool the system down.

3. Secure the coolant water through the tube by securing the coolant pumps.

4. Secure the water flow to the coolant sump tank.

5. To return the system to atmospheric temperature, slowly open the vent valve on the auxiliary condenser. Ensure no foreign material is in the vicinity of the vent valve so the system does not get contaminated.

6. If an emergency should arise, such as an overpressurization or breakage, ensure the heater power is secured <u>first!</u> Let the system cool down prior to checking for damage.

## APPENDIX C. UNCERTAINTY ANALYSIS

Uncertainties are always associated with any experimentally determined results. These uncertainties are a result of many different factors including the accuracy of measuring devices, calibration of a device, and operator experience. Although the uncertainty of a single measurement may be small, when combined with other measurements that have small uncertainties into a data reduction scheme, the effect may be to generate a large uncertainty in the final result.

The uncertainties can be estimated by using a propagation of error technique derived by Kline and McClintock [Ref. 33]. The uncertainty in a quantity, R, is a function of those variables that are used to determine that quantity. So the uncertainty of R can be represented as follows:

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} W_1\right)^2 + \left(\frac{\partial R}{\partial x_2} W_2\right)^2 + \ldots\ldots + \left(\frac{\partial R}{\partial x_n} W_n\right)^2\right] \qquad \text{(C.1)}$$

where:

$W_R$ = the uncertainty of the desired dependent variable

$x_1, x_2, \ldots, x_n$ = the measured independent variables

$W_1, W_2, \ldots, W_n$ = the uncertainties of the measured variables

A complete description for the uncertainty analysis is given in Georgiadis [Ref. 34]. A program, originally designed

by Mitrou [Ref. 9], was used to calculate the uncertainties for this experiment. Sample outputs of the uncertainty evaluations are enclosed.

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMVNC1 | | |
| Pressure Condition: | Vacuum | | |
| Vapor Temperature | = | 48.626 | (Deg C) |
| Water Flow Rate (%) | = | 80.00 | |
| Water Velocity | = | 4.32 | (m/s) |
| Heat Flux | = | 1.461E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 385.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0179 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 0.81 |
| Reynolds Number, Re | 1.14 |
| Heat Flux, q | 1.66 |
| Log-Mean-Tem Diff, LMTD | 1.38 |
| Wall Resistance, Rw | 2.67 |
| Overall H.T.C., Uo | 2.16 |
| Water-Side H.T.C., Hi | 11.22 |
| Vapor-Side H.T.C., Ho | 11.87 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMVNC1 | | |
| Pressure Condition: | Vacuum | | |
| Vapor Temperature | = | 48.619 | (Deg C) |
| Water Flow Rate (%) | = | 20.00 | |
| Water Velocity | = | 1.16 | (m/s) |
| Heat Flux | = | 8.492E+04 | (W/m^2) |
| Tube-metal thermal conduc. | = | 385.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0179 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 3.01 |
| Reynolds Number, Re | 3.12 |
| Heat Flux, q | 3.11 |
| Log-Mean-Tem Diff, LMTD | .64 |
| Wall Resistance, Rw | 2.67 |
| Overall H.T.C., Uo | 3.18 |
| Water-Side H.T.C., Hi | 11.46 |
| Vapor-Side H.T.C., Ho | 43.62 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMVHC1 | | |
| Pressure Condition: | Vacuum | | |
| Vapor Temperature | = | 48.745 | (Deg C) |
| Water Flow Rate (%) | = | 80.00 | |
| Water Velocity | = | 4.32 | (m/s) |
| Heat Flux | = | 1.840E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 385.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0415 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 0.81 |
| Reynolds Number, Re | 1.15 |
| Heat Flux, q | 1.43 |
| Log-Mean-Tem Diff, LMTD | 1.10 |
| Wall Resistance, Rw | 2.67 |
| Overall H.T.C., Uo | 1.81 |
| Water-Side H.T.C., Hi | 4.92 |
| Vapor-Side H.T.C., Ho | 3.41 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMVHC1 | | |
| Pressure Condition: | Vacuum | | |
| Vapor Temperature | = | 48.733 | (Deg C) |
| Water Flow Rate (%) | = | 20.00 | |
| Water Velocity | = | 1.16 | (m/s) |
| Heat Flux | = | 1.251E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 385.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0415 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 3.02 |
| Reynolds Number, Re | 3.13 |
| Heat Flux, q | 3.08 |
| Log-Mean-Tem Diff, LMTD | .43 |
| Wall Resistance, Rw | 2.67 |
| Overall H.T.C., Uo | 3.11 |
| Water-Side H.T.C., Hi | 5.44 |
| Vapor-Side H.T.C., Ho | 10.09 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMANC1 | | |
| Pressure Condition: | Atmospheric (101 kPa) | | |
| Vapor Temperature | = | 99.919 | (Deg C) |
| Water Flow Rate (%) | = | 80.00 | |
| Water Velocity | = | 4.31 | (m/s) |
| Heat Flux | = | 4.227E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 385.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0193 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 0.81 |
| Reynolds Number, Re | 1.16 |
| Heat Flux, q | 1.04 |
| Log-Mean-Tem Diff, LMTD | .48 |
| Wall Resistance, Rw | 2.67 |
| Overall H.T.C., Uo | 1.14 |
| Water-Side H.T.C., Hi | 10.41 |
| Vapor-Side H.T.C., Ho | 7.38 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMANC1 | | |
| Pressure Condition: | Atmospheric (101 kPa) | | |
| Vapor Temperature | = | 100.024 | (Deg C) |
| Water Flow Rate (%) | = | 20.00 | |
| Water Velocity | = | 1.16 | (m/s) |
| Heat Flux | = | 2.757E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 385.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0193 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 3.02 |
| Reynolds Number, Re | 3.14 |
| Heat Flux, q | 3.06 |
| Log-Mean-Tem Diff, LMTD | .20 |
| Wall Resistance, Rw | 2.67 |
| Overall H.T.C., Uo | 3.06 |
| Water-Side H.T.C., Hi | 10.67 |
| Vapor-Side H.T.C., Ho | 27.24 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMAHC1 | | |
| Pressure Condition: | Atmospheric (101 kPa) | | |
| Vapor Temperature | = | 99.887 | (Deg C) |
| Water Flow Rate (%) | = | 80.00 | |
| Water Velocity | = | 4.31 | (m/s) |
| Heat Flux | = | 4.952E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 385.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0442 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 0.81 |
| Reynolds Number, Re | 1.17 |
| Heat Flux, q | 1.01 |
| Log-Mean-Tem Diff, LMTD | .41 |
| Wall Resistance, Rw | 2.67 |
| Overall H.T.C., Uo | 1.09 |
| Water-Side H.T.C., Hi | 4.64 |
| Vapor-Side H.T.C., Ho | 2.01 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMAHC1 | | |
| Pressure Condition: | Atmospheric (101 kPa) | | |
| Vapor Temperature | = | 99.879 | (Deg C) |
| Water Flow Rate (%) | = | 20.00 | |
| Water Velocity | = | 1.15 | (m/s) |
| Heat Flux | = | 3.805E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 385.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0442 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 3.03 |
| Reynolds Number, Re | 3.15 |
| Heat Flux, q | 3.06 |
| Log-Mean-Tem Diff, LMTD | .14 |
| Wall Resistance, Rw | 2.67 |
| Overall H.T.C., Uo | 3.07 |
| Water-Side H.T.C., Hi | 5.20 |
| Vapor-Side H.T.C., Ho | 7.68 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMVNT3 | | |
| Pressure Condition: | Vacuum | | |
| Vapor Temperature | = | 48.670 | (Deg C) |
| Water Flow Rate (%) | = | 80.00 | |
| Water Velocity | = | 3.63 | (m/s) |
| Heat Flux | = | 1.248E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 21.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0179 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 0.80 |
| Reynolds Number, Re | 1.12 |
| Heat Flux, q | 2.16 |
| Log-Mean-Tem Diff, LMTD | 1.95 |
| Wall Resistance, Rw | 5.09 |
| Overall H.T.C., Uo | 2.91 |
| Water-Side H.T.C., Hi | 16.79 |
| Vapor-Side H.T.C., Ho | 17.15 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMVNT3 | | |
| Pressure Condition: | Vacuum | | |
| Vapor Temperature | = | 48.736 | (Deg C) |
| Water Flow Rate (%) | = | 20.00 | |
| Water Velocity | = | 0.97 | (m/s) |
| Heat Flux | = | 7.590E+04 | (W/m^2) |
| Tube-metal thermal conduc. | = | 21.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0179 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 3.01 |
| Reynolds Number, Re | 3.11 |
| Heat Flux, q | 3.16 |
| Log-Mean-Tem Diff, LMTD | .86 |
| Wall Resistance, Rw | 5.09 |
| Overall H.T.C., Uo | 3.28 |
| Water-Side H.T.C., Hi | 16.95 |
| Vapor-Side H.T.C., Ho | 58.73 |

Heat Flux =
DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | | |
|---|---|---|---|---|
| File Name: | FONMVHT3 | | | |
| Pressure Condition: | Vacuum | | | |
| Vapor Temperature | | = | 48.651 | (Deg C) |
| Water Flow Rate (%) | | = | 20.00 | |
| Water Velocity | | = | 0.97 | (m/s) |
| Heat Flux | | = | 1.082E+05 | (W/m^2) |
| Tube-metal thermal conduc. | | = | 21.0 | (W/m.K) |
| Sieder-Tate constant | | = | 0.0431 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 3.01 |
| Reynolds Number, Re | 3.11 |
| Heat Flux, q | 3.10 |
| Log-Mean-Tem Diff, LMTD | .60 |
| Wall Resistance, Rw | 5.09 |
| Overall H.T.C., Uo | 3.16 |
| Water-Side H.T.C., Hi | 7.40 |
| Vapor-Side H.T.C., Ho | 12.54 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | | |
|---|---|---|---|---|
| File Name: | FONMVHT3 | | | |
| Pressure Condition: | Vacuum | | | |
| Vapor Temperature | | = | 48.684 | (Deg C) |
| Water Flow Rate (%) | | = | 80.00 | |
| Water Velocity | | = | 3.63 | (m/s) |
| Heat Flux | | = | 1.471E+05 | (W/m^2) |
| Tube-metal thermal conduc. | | = | 21.0 | (W/m.K) |
| Sieder-Tate constant | | = | 0.0431 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 0.80 |
| Reynolds Number, Re | 1.12 |
| Heat Flux, q | 1.90 |
| Log-Mean-Tem Diff, LMTD | 1.66 |
| Wall Resistance, Rw | 5.09 |
| Overall H.T.C., Uo | 2.52 |
| Water-Side H.T.C., Hi | 7.03 |
| Vapor-Side H.T.C., Ho | 6.07 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMANTS | | |
| Pressure Condition: | Atmospheric (101 kPa) | | |
| Vapor Temperature | = | 100.026 | (Deg C) |
| Water Flow Rate (%) | = | 80.00 | |
| Water Velocity | = | 3.63 | (m/s) |
| Heat Flux | = | 3.632E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 21.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0191 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 0.81 |
| Reynolds Number, Re | 1.14 |
| Heat Flux, q | 1.14 |
| Log-Mean-Tem Diff, LMTD | .67 |
| Wall Resistance, Rw | 5.09 |
| Overall H.T.C., Uo | 1.32 |
| Water-Side H.T.C., Hi | 15.74 |
| Vapor-Side H.T.C., Ho | 11.68 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMANTS | | |
| Pressure Condition: | Atmospheric (101 kPa) | | |
| Vapor Temperature | = | 99.958 | (Deg C) |
| Water Flow Rate (%) | = | 20.00 | |
| Water Velocity | = | 0.97 | (m/s) |
| Heat Flux | = | 2.413E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 21.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0191 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 3.02 |
| Reynolds Number, Re | 3.12 |
| Heat Flux, q | 3.06 |
| Log-Mean-Tem Diff, LMTD | .27 |
| Wall Resistance, Rw | 5.09 |
| Overall H.T.C., Uo | 3.07 |
| Water-Side H.T.C., Hi | 15.91 |
| Vapor-Side H.T.C., Ho | 41.47 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMAHT6 | | |
| Pressure Condition: | Atmospheric (101 kPa) | | |
| Vapor Temperature | = | 100.020 | (Deg C) |
| Water Flow Rate (%) | = | 80.00 | |
| Water Velocity | = | 3.62 | (m/s) |
| Heat Flux | = | 4.049E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 21.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0403 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 0.81 |
| Reynolds Number, Re | 1.15 |
| Heat Flux, q | 1.10 |
| Log-Mean-Tem Diff, LMTD | .60 |
| Wall Resistance, Rw | 5.09 |
| Overall H.T.C., Uo | 1.25 |
| Water-Side H.T.C., Hi | 7.51 |
| Vapor-Side H.T.C., Ho | 4.13 |

DATA FOR THE UNCERTAINTY ANALYSIS:

| | | | |
|---|---|---|---|
| File Name: | FONMAHT6 | | |
| Pressure Condition: | Atmospheric (101 kPa) | | |
| Vapor Temperature | = | 99.922 | (Deg C) |
| Water Flow Rate (%) | = | 20.00 | |
| Water Velocity | = | 0.97 | (m/s) |
| Heat Flux | = | 3.120E+05 | (W/m^2) |
| Tube-metal thermal conduc. | = | 21.0 | (W/m.K) |
| Sieder-Tate constant | = | 0.0403 | |

UNCERTAINTY ANALYSIS:

| VARIABLE | PERCENT UNCERTAINTY |
|---|---|
| Mass Flow Rate, Md | 3.03 |
| Reynolds Number, Re | 3.15 |
| Heat Flux, q | 3.07 |
| Log-Mean-Tem Diff, LMTD | .21 |
| Wall Resistance, Rw | 5.09 |
| Overall H.T.C., Uo | 3.08 |
| Water-Side H.T.C., Hi | 7.87 |
| Vapor-Side H.T.C., Ho | 11.47 |

# APPENDIX D. DATA RUNS

The names of the data files are listed in Tables 2 through 13 in Chapter 5. The data files presented in this appendix have been reprocessed using the Petukhov-Popov [Ref. 29] form of the inside heat transfer correlation. The data have been printed out in the short form format.

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHT1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.96 (mm)
Outside diameter, Do = 15.95 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3715
Alpha (based on Nusselt (Tdel)) = 0.7801
Enhancement (q) = .963
Enhancement (Del-T) = .972

| Data # | Vw (m/s) | Uo (W/m^2-k) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.66 | 5.352E+03 | 9.727E+03 | 4.334E+05 | 44.55 | 100.11 |
| 2 | 3.21 | 5.297E+03 | 9.985E+03 | 4.242E+05 | 42.91 | 99.96 |
| 3 | 2.76 | 5.210E+03 | 1.003E+04 | 4.132E+05 | 41.19 | 99.97 |
| 4 | 2.31 | 5.054E+03 | 1.005E+04 | 3.969E+05 | 39.45 | 100.05 |
| 5 | 1.87 | 4.895E+03 | 1.030E+04 | 3.792E+05 | 36.81 | 100.01 |
| 6 | 1.42 | 4.639E+03 | 1.056E+04 | 3.546E+05 | 33.58 | 100.04 |
| 7 | 0.97 | 4.275E+03 | 1.128E+04 | 3.220E+05 | 28.55 | 100.07 |
| 8 | 1.42 | 4.619E+03 | 1.039E+04 | 3.486E+05 | 33.54 | 100.00 |
| 9 | 1.86 | 4.874E+03 | 1.011E+04 | 3.675E+05 | 36.35 | 99.94 |
| 10 | 2.30 | 5.091E+03 | 1.009E+04 | 3.845E+05 | 38.15 | 100.05 |
| 11 | 2.75 | 5.232E+03 | 9.967E+03 | 3.944E+05 | 39.57 | 99.99 |
| 12 | 3.19 | 5.335E+03 | 9.860E+03 | 4.014E+05 | 40.71 | 99.95 |
| 13 | 3.63 | 5.391E+03 | 9.692E+03 | 4.055E+05 | 41.84 | 100.05 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1043E-01
Intercept = 7.7997E+05

Least-squares line for q = a*delta-T^b
a = 2.5179E+04
b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT1

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3833
Alpha (based on Nusselt (Tdel)) = 0.7740
Enhancement (q) = .953
Enhancement (Del-T) = .965

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.65 | 5.332E+03 | 9.587E+03 | 4.209E+05 | 43.91 | 100.0 |
| 2 | 3.20 | 5.312E+03 | 9.853E+03 | 4.147E+05 | 42.08 | 99.9 |
| 3 | 2.75 | 5.197E+03 | 9.887E+03 | 4.018E+05 | 40.54 | 100.0 |
| 4 | 2.31 | 5.069E+03 | 1.000E+04 | 3.875E+05 | 38.74 | 100.0 |
| 5 | 1.42 | 4.657E+03 | 1.049E+04 | 3.474E+05 | 33.12 | 100.0 |
| 6 | 0.97 | 4.290E+03 | 1.109E+04 | 3.150E+05 | 28.40 | 99.9 |
| 7 | 1.41 | 4.675E+03 | 1.054E+04 | 3.459E+05 | 32.83 | 100.0 |
| 8 | 1.86 | 4.940E+03 | 1.029E+04 | 3.655E+05 | 35.51 | 99.9 |
| 9 | 2.30 | 5.114E+03 | 1.008E+04 | 3.785E+05 | 37.54 | 100.0 |
| 10 | 2.74 | 5.245E+03 | 9.944E+03 | 3.882E+05 | 39.04 | 100.0 |
| 11 | 3.18 | 5.329E+03 | 9.763E+03 | 3.939E+05 | 40.26 | 100.0 |
| 12 | 3.62 | 5.456E+03 | 9.657E+03 | 4.022E+05 | 40.30 | 99.9 |
| 13 | 3.62 | 5.448E+03 | 9.823E+03 | 4.006E+05 | 40.76 | 99.9 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1793E-01
Intercept = 7.2191E+05

Least-squares line for q = a*delta-T b
a = 2.4999E+04
b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT2

NOTE: 13 x-y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHT3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3923
Alpha (based on Nusselt (Tdel)) = 0.7551
Enhancement (q) = .922
Enhancement (Del-T) = .941

| Data # | Vw (m/s) | Uc (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.62 | 5.411E+03 | 9.701E+03 | 4.000E+05 | 41.23 | 99.93 |
| 2 | 3.18 | 5.316E+03 | 9.717E+03 | 3.913E+05 | 40.27 | 100.01 |
| 3 | 2.74 | 5.185E+03 | 9.693E+03 | 3.796E+05 | 39.16 | 100.02 |
| 4 | 2.29 | 5.048E+03 | 9.766E+03 | 3.674E+05 | 37.63 | 100.05 |
| 5 | 1.85 | 4.872E+03 | 9.904E+03 | 3.520E+05 | 35.54 | 99.93 |
| 6 | 1.41 | 4.633E+03 | 1.017E+04 | 3.322E+05 | 32.68 | 99.96 |
| 7 | 1.19 | 4.494E+03 | 1.050E+04 | 3.205E+05 | 30.53 | 100.03 |
| 8 | 0.97 | 4.322E+03 | 1.105E+04 | 3.063E+05 | 27.72 | 100.08 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1533E-01
Intercept = 7.7848E+05

Least-squares line for q = a*delta-T^b
a = 2.4500E+04
b = 7.5000E-01

NOTE: 08 data points were stored in file FONMAHT3

NOTE: 08 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHT4
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4099
Alpha (based on Nusselt (Tdel)) = 0.7484
Enhancement (q) = .911
Enhancement (Del-T) = .933

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 0.97 | 4.236E+03 | 1.079E+04 | 3.171E+05 | 29.40 | 100.04 |
| 2 | 1.42 | 4.556E+03 | 9.950E+03 | 3.427E+05 | 34.44 | 100.03 |
| 3 | 1.64 | 4.702E+03 | 9.843E+03 | 3.517E+05 | 35.74 | 99.99 |
| 4 | 2.08 | 4.919E+03 | 9.698E+03 | 3.678E+05 | 37.92 | 99.98 |
| 5 | 2.52 | 5.108E+03 | 9.703E+03 | 3.809E+05 | 39.26 | 100.03 |
| 6 | 2.96 | 5.221E+03 | 9.537E+03 | 3.881E+05 | 40.44 | 100.04 |
| 7 | 3.40 | 5.329E+03 | 9.570E+03 | 3.936E+05 | 41.13 | 99.99 |
| 8 | 3.62 | 5.358E+03 | 9.505E+03 | 3.946E+05 | 41.52 | 100.03 |
| 9 | 3.18 | 5.295E+03 | 9.612E+03 | 3.874E+05 | 40.30 | 100.10 |
| 10 | 2.73 | 5.186E+03 | 9.657E+03 | 3.774E+05 | 39.07 | 100.03 |
| 11 | 2.29 | 5.010E+03 | 9.583E+03 | 3.627E+05 | 37.85 | 100.02 |
| 12 | 1.63 | 4.739E+03 | 9.650E+03 | 3.398E+05 | 34.50 | 100.02 |
| 13 | 0.97 | 4.296E+03 | 1.072E+04 | 3.025E+05 | 29.21 | 100.03 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1639E-01
Intercept = 7.7629E+05

Least-squares line for q = a*delta-T^b
a = 2.4222E+04
b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT4

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHTS
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petuknov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2011
Alpha (based on Nusselt (Tdel)) = 0.7700
Enhancement (q) = .947
Ennancement (Del-T) = .960

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.64 | 5.268E+03 | 9.574E+03 | 4.057E+05 | 42.38 | 99.90 |
| 2 | 3.19 | 5.273E+03 | 9.935E+03 | 4.002E+05 | 40.23 | 99.96 |
| 3 | 2.74 | 5.200E+03 | 1.014E+04 | 3.896E+05 | 38.41 | 99.95 |
| 4 | 2.30 | 5.035E+03 | 1.015E+04 | 3.717E+05 | 36.62 | 99.92 |
| 5 | 1.85 | 4.822E+03 | 1.018E+04 | 3.509E+05 | 34.47 | 100.00 |
| 6 | 1.41 | 4.599E+03 | 1.064E+04 | 3.313E+05 | 31.14 | 99.99 |
| 7 | 0.97 | 4.218E+03 | 1.132E+04 | 2.994E+05 | 25.44 | 100.05 |
| 8 | 1.19 | 4.423E+03 | 1.084E+04 | 3.152E+05 | 29.08 | 99.97 |
| 9 | 1.63 | 4.770E+03 | 1.058E+04 | 3.428E+05 | 32.40 | 100.02 |
| 10 | 2.07 | 4.992E+03 | 1.034E+04 | 3.595E+05 | 34.77 | 99.93 |
| 11 | 2.51 | 5.159E+03 | 1.020E+04 | 3.730E+05 | 36.56 | 100.02 |
| 12 | 2.95 | 5.253E+03 | 9.979E+03 | 3.800E+05 | 38.06 | 99.92 |
| 13 | 3.39 | 5.333E+03 | 9.932E+03 | 3.862E+05 | 39.23 | 99.96 |
| 14 | 3.61 | 5.394E+03 | 9.860E+03 | 3.906E+05 | 39.63 | 100.27 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1391E-01
Intercept = 7.7984E+05

Least-squares line for q = a*delta-T^b
a = 2.4990E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHTS

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMAHT6
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.96 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.5406
Alpha (based on Nusselt (Tdel)) =  0.7758
Enhancement (q)                   =   .956
Enhancement (Del-T)               =   .967

Data    Vw        Uo           Ho           Qp           Tcf     Ts
 #     (m/s)   (W/m^2-K)    (W/m^2-K)    (W/m^2)        (C)     (C
  1     3.62   5.523E+03    9.871E+03   4.049E+05     41.01  100.02
  2     3.18   5.441E+03    9.923E+03   3.969E+05     40.00  100.05
  3     2.73   5.369E+03    1.010E+04   3.892E+05     38.54   99.99
  4     2.29   5.247E+03    1.023E+04   3.765E+05     36.81   99.80
  5     2.07   5.133E+03    1.016E+04   3.680E+05     36.21   99.99
  6     1.41   4.926E+03    1.064E+04   3.410E+05     32.06   99.79
  7     0.97   4.458E+03    1.121E+04   3.120E+05     27.93   99.92
  8     1.41   4.816E+03    1.053E+04   3.411E+05     32.22   99.92
  9     1.85   5.089E+03    1.044E+04   3.630E+05     34.76   99.99
 10     2.29   5.230E+03    1.015E+04   3.744E+05     35.89   99.96
 11     2.51   5.320E+03    1.017E+04   3.806E+05     37.44   99.94
 12     2.73   5.411E+03    1.022E+04   3.876E+05     37.93   99.97
 13     3.17   5.461E+03    9.960E+03   3.920E+05     38.36  100.04

Least-Squares Line for Ho vs q curve:
  Slope       = -3.0354E-01
  Intercept   =  7.7703E+05

Least-squares line for q = a*delta-T^b
  a =  2.5179E+04
  b =  7.5000E-01


NOTE: 13 data points were stored in file FONMAHT5

NOTE: 13 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHT7
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.66 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.5109
Alpha (based on Nusselt (Tdel)) = 0.7924
Enhancement (q) = .983
Enhancement (Del-T) = .987

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.64 | 5.512E+03 | 9.985E+03 | 4.286E+05 | 42.93 | 100.05 |
| 2 | 3.19 | 5.415E+03 | 9.976E+03 | 4.142E+05 | 41.52 | 99.94 |
| 3 | 2.75 | 5.348E+03 | 1.019E+04 | 4.048E+05 | 39.79 | 99.90 |
| 4 | 2.52 | 5.309E+03 | 1.030E+04 | 3.998E+05 | 38.81 | 100.03 |
| 5 | 2.30 | 5.239E+03 | 1.037E+04 | 3.923E+05 | 37.84 | 99.94 |
| 6 | 2.08 | 5.150E+03 | 1.041E+04 | 3.847E+05 | 36.94 | 100.05 |
| 7 | 1.86 | 5.037E+03 | 1.043E+04 | 3.742E+05 | 35.87 | 99.91 |
| 8 | 1.41 | 4.791E+03 | 1.073E+04 | 3.538E+05 | 32.97 | 99.96 |
| 9 | 0.97 | 4.451E+03 | 1.157E+04 | 3.252E+05 | 28.10 | 100.06 |
| 10 | 1.41 | 4.799E+03 | 1.078E+04 | 3.551E+05 | 32.95 | 100.04 |
| 11 | 1.86 | 5.042E+03 | 1.045E+04 | 3.752E+05 | 35.99 | 100.03 |
| 12 | 2.30 | 5.231E+03 | 1.032E+04 | 3.896E+05 | 37.76 | 99.93 |
| 13 | 2.74 | 5.372E+03 | 1.022E+04 | 4.007E+05 | 39.20 | 99.93 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1602E-01
Intercept = 7.8428E+05

Least-squares line for q = a*delta-T b
a = 2.5669E+04
b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT7

NOTE. 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMANT1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.66 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.2114

Alpha (based on Nusselt (Tdel)) = 0.7504

Enhancement (q) = .941

Enhancement (Del-T) = .955

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 2.74 | 4.483E+03 | 1.050E+04 | 3.315E+05 | 31.56 | 100.02 |
| 2 | 2.51 | 4.399E+03 | 1.053E+04 | 3.200E+05 | 30.39 | 99.99 |
| 3 | 2.29 | 4.273E+03 | 1.051E+04 | 3.091E+05 | 29.42 | 100.05 |
| 4 | 2.07 | 4.147E+03 | 1.052E+04 | 2.971E+05 | 28.25 | 99.99 |
| 5 | 1.85 | 4.006E+03 | 1.056E+04 | 2.851E+05 | 26.95 | 99.90 |
| 6 | 1.41 | 3.687E+03 | 1.106E+04 | 2.609E+05 | 23.80 | 99.99 |
| 7 | 0.97 | 3.293E+03 | 1.293E+04 | 2.304E+05 | 17.81 | 99.38 |
| 8 | 1.41 | 3.687E+03 | 1.101E+04 | 2.594E+05 | 23.57 | 99.99 |
| 9 | 1.85 | 4.030E+03 | 1.066E+04 | 2.837E+05 | 26.60 | 99.95 |
| 10 | 2.07 | 4.183E+03 | 1.064E+04 | 2.949E+05 | 27.72 | 100.19 |
| 11 | 2.30 | 4.295E+03 | 1.076E+04 | 3.161E+05 | 29.38 | 99.81 |
| 12 | 2.74 | 4.450E+03 | 1.042E+04 | 3.356E+05 | 32.21 | 100.22 |
| 13 | 3.19 | 4.623E+03 | 1.037E+04 | 3.498E+05 | 33.7[illegible] | 99.89 |

Least-Squares Line for Ho vs q curve:

Slope = -2.6012E-01

Intercept = 7.6036E+05

Least-squares line for q = a*delta-T b

a = 2.4594E-04

b = 7.5000E-01

NOTE: 13 data points were stored in file FONMANT1

NOTE: 13 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMANT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.1849
Alpha (based on Nusselt (Tdel)) = 0.7603
Enhancement (q) = .957
Enhancement (Del-T) = .968

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.65 | 4.669E+03 | 1.022E+04 | 3.713E+05 | 36.34 | 99.99 |
| 2 | 3.20 | 4.572E+03 | 1.046E+04 | 3.566E+05 | 34.29 | 100.01 |
| 3 | 2.75 | 4.426E+03 | 1.064E+04 | 3.421E+05 | 32.15 | 100.01 |
| 4 | 2.31 | 4.226E+03 | 1.080E+04 | 3.226E+05 | 29.86 | 100.04 |
| 5 | 1.86 | 3.933E+03 | 1.073E+04 | 2.958E+05 | 27.57 | 99.34 |
| 6 | 1.41 | 3.615E+03 | 1.127E+04 | 2.686E+05 | 23.34 | 100.00 |
| 7 | 0.97 | 3.263E+03 | 1.396E+04 | 2.392E+05 | 17.06 | 99.93 |
| 8 | 1.19 | 3.387E+03 | 1.118E+04 | 2.454E+05 | 21.95 | 99.95 |
| 9 | 0.97 | 3.209E+03 | 1.261E+04 | 2.286E+05 | 18.15 | 99.93 |
| 10 | 1.19 | 3.399E+03 | 1.112E+04 | 2.424E+05 | 21.80 | 99.99 |
| 11 | 1.41 | 3.647E+03 | 1.115E+04 | 2.608E+05 | 23.39 | 99.99 |
| 12 | 1.85 | 4.000E+03 | 1.085E+04 | 2.868E+05 | 25.43 | 99.91 |
| 13 | 2.07 | 4.154E+03 | 1.082E+04 | 2.989E+05 | 27.52 | 100.11 |
| 14 | 2.29 | 4.286E+03 | 1.079E+04 | 3.082E+05 | 29.57 | 99.98 |
| 15 | 2.51 | 4.410E+03 | 1.077E+04 | 3.167E+05 | 29.40 | 99.97 |
| 16 | 2.73 | 4.530E+03 | 1.081E+04 | 3.249E+05 | 30.04 | 99.81 |

Least-Squares Line for Ho vs q curve:
Slope = -2.5701E-01
Intercept = 7.5050E-05

Least-squares line for q = a*delta-T^b
a = 2.5129E+04
b = 7.3000E-01

NOTE: 16 data points were stored in file FONMANT2

NOTE: 16 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMANT3
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.86 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  1.1636
Alpha (based on Nusselt (Toel)) =  0.7650
Ennancement (q)                    =   .965
Enhancement (Del-T)                =   .974
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 0.97 | 3.230E+03 | 1.310E+04 | 2.269E+05 | 17.32 | 99.88 |
| 2 | 1.41 | 3.652E+03 | 1.136E+04 | 2.595E+05 | 22.36 | 100.05 |
| 3 | 1.63 | 3.837E+03 | 1.113E+04 | 2.730E+05 | 24.53 | 99.92 |
| 4 | 1.85 | 4.008E+03 | 1.104E+04 | 2.857E+05 | 25.89 | 99.97 |
| 5 | 2.07 | 4.143E+03 | 1.087E+04 | 2.959E+05 | 27.21 | 99.96 |
| 6 | 2.29 | 4.236E+03 | 1.057E+04 | 3.028E+05 | 28.54 | 99.93 |
| 7 | 2.51 | 4.424E+03 | 1.096E+04 | 3.165E+05 | 28.37 | 99.99 |
| 8 | 2.73 | 4.513E+03 | 1.082E+04 | 3.229E+05 | 29.63 | 99.92 |
| 9 | 2.95 | 4.627E+03 | 1.088E+04 | 3.308E+05 | 30.41 | 99.92 |
| 10 | 3.17 | 4.745E+03 | 1.101E+04 | 3.394E-05 | 30.82 | 99.94 |
| 11 | 3.61 | 4.815E+03 | 1.055E+04 | 3.457E-05 | 32.76 | 100.01 |
| 12 | 2.29 | 4.291E+03 | 1.092E+04 | 3.070E-05 | 28.12 | 100.04 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.4792E-01
  Intercept   =  7.5835E+05

Least-squares line for q = a*delta-T b
  a =  2.5250E+04
  b =  7.5000E-01


NOTE: 12 data points were stored in file FONMANT3

NOTE: 12 x-y pairs were stored in data file
```

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMANT4
      This analysis includes end-fin effect
      Thermal conductivity       =  21.0 (W/m.K)
      Inside diameter, Di        = 13.86 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  1.1611
Alpha (based on Nusselt (Tdel)) =  0.7548
Enhancement (q)                  =   .965
Enhancement (Del-T)              =   .974
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.62 | 4.778E+03 | 1.036E+04 | 3.479E+05 | 33.59 | 100.00 |
| 2 | 0.97 | 3.192E+03 | 1.259E+04 | 2.299E+05 | 19.26 | 100.06 |
| 3 | 1.85 | 3.969E+03 | 1.083E+04 | 2.910E+05 | 26.87 | 99.97 |
| 4 | 2.30 | 4.246E+03 | 1.072E+04 | 3.133E+05 | 29.23 | 100.02 |
| 5 | 2.74 | 4.465E+03 | 1.064E+04 | 3.317E+05 | 31.19 | 100.21 |
| 6 | 3.18 | 4.648E+03 | 1.059E+04 | 3.453E+05 | 32.58 | 99.99 |
| 7 | 3.63 | 4.792E+03 | 1.047E+04 | 3.558E+05 | 33.99 | 99.96 |
| 8 | 3.62 | 4.755E+03 | 1.030E+04 | 3.525E+05 | 34.21 | 100.34 |
| 9 | 3.18 | 4.663E+03 | 1.061E+04 | 3.433E+05 | 32.36 | 100.24 |
| 10 | 2.74 | 4.506E+03 | 1.079E+04 | 3.294E+05 | 30.52 | 99.99 |
| 11 | 2.29 | 4.257E+03 | 1.077E+04 | 3.110E+05 | 28.88 | 100.01 |
| 12 | 1.85 | 3.971E+03 | 1.077E+04 | 2.895E+05 | 26.89 | 100.25 |
| 13 | 1.41 | 3.628E+03 | 1.116E+04 | 2.626E+05 | 23.54 | 99.92 |
| 14 | 0.97 | 3.193E+03 | 1.266E+04 | 2.305E+05 | 19.21 | 99.99 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.5738E-01
  Intercept   =  7.6096E+05

Least-squares line for q = a*delta-T^b
  a =  2.5144E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMANT4

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMANT5
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.88 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.2370
Alpha (based on Nusselt (Tdel)) = 0.7863
Enhancement (q) = 1.001
Enhancement (Del-T) = 1.001

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 4.877E+03 | 1.061E+04 | 3.632E+05 | 34.25 | 100.03 |
| 2 | 3.18 | 4.755E+03 | 1.076E+04 | 3.513E+05 | 32.64 | 99.97 |
| 3 | 2.74 | 4.591E+03 | 1.093E+04 | 3.394E+05 | 31.06 | 100.00 |
| 4 | 2.30 | 4.374E+03 | 1.107E+04 | 3.234E+05 | 29.22 | 100.00 |
| 5 | 1.86 | 4.083E+03 | 1.115E+04 | 3.021E+05 | 27.08 | 100.02 |
| 6 | 1.41 | 3.723E+03 | 1.149E+04 | 2.750E+05 | 23.95 | 100.00 |
| 7 | 0.97 | 3.287E+03 | 1.309E+04 | 2.413E+05 | 18.43 | 99.96 |
| 8 | 1.41 | 3.720E+03 | 1.148E+04 | 2.755E+05 | 23.99 | 99.97 |
| 9 | 0.97 | 3.283E+03 | 1.308E+04 | 2.416E+05 | 18.47 | 99.95 |
| 10 | 1.86 | 4.081E+03 | 1.120E+04 | 3.040E+05 | 27.15 | 100.01 |
| 11 | 2.30 | 4.380E+03 | 1.117E+04 | 3.267E+05 | 29.26 | 99.99 |
| 12 | 2.74 | 4.572E+03 | 1.091E+04 | 3.436E+05 | 31.49 | 100.04 |
| 13 | 3.19 | 4.748E+03 | 1.081E+04 | 3.573E+05 | 33.04 | 100.05 |
| 14 | 3.63 | 4.873E+03 | 1.064E+04 | 3.664E+05 | 34.45 | 99.95 |
| 15 | 2.30 | 4.355E+03 | 1.103E+04 | 3.263E+05 | 29.57 | 100.03 |
| 16 | 0.97 | 3.256E+03 | 1.278E+04 | 2.411E+05 | 18.86 | 99.94 |

Least-Squares Line for Ho vs q curve:
Slope = -2.5021E-01
Intercept = 7.6397E+05

Least-squares line for q = a*delta-T^b
a = 2.5924E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMANT5

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVHT3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.66 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.5472
Alpha (based on Nusselt (Tdel)) = 0.7483
Enhancement (q) = .824
Enhancement (Del-T) = .865

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 0.97 | 4.574E+03 | 1.251E+04 | 1.082E+05 | 8.65 | 48.65 |
| 2 | 1.64 | 5.049E+03 | 1.115E+04 | 1.231E+05 | 11.04 | 48.64 |
| 3 | 2.08 | 5.282E+03 | 1.096E+04 | 1.303E+05 | 11.89 | 48.68 |
| 4 | 2.52 | 5.490E+03 | 1.098E+04 | 1.362E+05 | 12.40 | 48.57 |
| 5 | 2.97 | 5.652E+03 | 1.099E+04 | 1.407E+05 | 12.80 | 48.57 |
| 6 | 3.41 | 5.797E+03 | 1.106E+04 | 1.446E+05 | 13.08 | 48.65 |
| 7 | 3.63 | 5.871E+03 | 1.113E+04 | 1.471E+05 | 13.22 | 48.68 |
| 8 | 3.63 | 5.815E+03 | 1.093E+04 | 1.457E+05 | 13.33 | 48.70 |
| 9 | 3.41 | 5.774E+03 | 1.098E+04 | 1.445E+05 | 13.16 | 48.72 |
| 10 | 2.97 | 5.690E+03 | 1.114E+04 | 1.412E+05 | 12.67 | 48.53 |
| 11 | 2.08 | 5.275E+03 | 1.092E+04 | 1.297E+05 | 11.87 | 48.57 |
| 12 | 1.64 | 5.052E+03 | 1.116E+04 | 1.232E+05 | 11.04 | 48.72 |
| 13 | 1.19 | 4.698E+03 | 1.142E+04 | 1.130E+05 | 9.39 | 48.59 |
| 14 | 0.97 | 4.474E+03 | 1.130E+04 | 1.060E+05 | 8.99 | 48.62 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1158E-01
Intercept = 5.8173E+05

Least-squares line for q = a*delta-T^b
a = 2.0703E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHT3

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVHT4
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2780
Alpha (based on Nusselt (Tdel)) = 0.7900
Enhancement (q) = .885
Enhancement (Del-T) = .913

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.64 | 5.867E+03 | 1.159E+04 | 1.505E+05 | 12.98 | 48.68 |
| 2 | 3.19 | 5.759E+03 | 1.167E+04 | 1.456E+05 | 12.48 | 48.65 |
| 3 | 2.75 | 5.583E+03 | 1.158E+04 | 1.392E+05 | 12.01 | 48.63 |
| 4 | 2.52 | 5.559E+03 | 1.189E+04 | 1.380E+05 | 11.60 | 48.67 |
| 5 | 2.30 | 5.421E+03 | 1.175E+04 | 1.339E+05 | 11.39 | 48.68 |
| 6 | 2.08 | 5.260E+03 | 1.165E+04 | 1.299E+05 | 11.14 | 48.67 |
| 7 | 1.86 | 5.203E+03 | 1.198E+04 | 1.273E+05 | 10.62 | 48.64 |
| 8 | 1.42 | 4.908E+03 | 1.242E+04 | 1.192E+05 | 9.59 | 48.70 |
| 9 | 0.97 | 4.453E+03 | 1.326E+04 | 1.066E+05 | 8.04 | 48.74 |
| 10 | 1.42 | 4.907E+03 | 1.243E+04 | 1.196E+05 | 9.62 | 48.65 |
| 11 | 1.86 | 5.161E+03 | 1.178E+04 | 1.274E+05 | 10.82 | 48.67 |
| 12 | 2.30 | 5.424E+03 | 1.178E+04 | 1.350E+05 | 11.46 | 48.68 |
| 13 | 2.53 | 5.530E+03 | 1.177E+04 | 1.380E+05 | 11.73 | 48.69 |
| 14 | 2.75 | 5.607E+03 | 1.169E+04 | 1.403E+05 | 12.01 | 48.74 |
| 15 | 3.19 | 5.731E+03 | 1.154E+04 | 1.435E+05 | 12.43 | 48.56 |
| 16 | 3.63 | 5.831E+03 | 1.143E+04 | 1.464E+05 | 12.81 | 48.68 |

Least-Squares Line for Ho vs q curve:
Slope = -3.2707E-01
Intercept = 5.8591E+05

Least-squares line for q = a*delta-T^b
a = 2.1743E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVHT4

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVHTS
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4221
Alpha (based on Nusselt (Tdel)) = 0.7627
Enhancement (q) = .845
Enhancement (Del-T) = .881

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 0.97 | 4.402E+03 | 1.202E+04 | 1.082E+05 | 9.00 | 48.67 |
| 2 | 1.42 | 4.872E+03 | 1.165E+04 | 1.215E+05 | 10.43 | 48.64 |
| 3 | 1.86 | 5.173E+03 | 1.141E+04 | 1.301E+05 | 11.41 | 48.65 |
| 4 | 2.08 | 5.274E+03 | 1.125E+04 | 1.331E+05 | 11.83 | 48.72 |
| 5 | 2.30 | 5.395E+03 | 1.128E+04 | 1.362E+05 | 12.07 | 48.70 |
| 6 | 2.53 | 5.422E+03 | 1.097E+04 | 1.366E+05 | 12.45 | 48.65 |
| 7 | 2.75 | 5.510E+03 | 1.098E+04 | 1.395E+05 | 12.71 | 48.76 |
| 8 | 3.19 | 5.676E+03 | 1.105E+04 | 1.440E+05 | 13.02 | 48.78 |
| 9 | 3.64 | 5.745E+03 | 1.087E+04 | 1.461E+05 | 13.44 | 48.78 |
| 10 | 3.19 | 5.741E+03 | 1.130E+04 | 1.453E+05 | 12.86 | 48.82 |
| 11 | 2.75 | 5.600E+03 | 1.133E+04 | 1.404E+05 | 12.38 | 48.69 |
| 12 | 2.30 | 5.390E+03 | 1.124E+04 | 1.347E+05 | 11.96 | 48.73 |
| 13 | 2.08 | 5.317E+03 | 1.143E+04 | 1.324E+05 | 11.59 | 48.72 |
| 14 | 1.86 | 5.202E-03 | 1.152E+04 | 1.296E+05 | 11.24 | 48.80 |
| 15 | 1.42 | 4.874E-03 | 1.162E+04 | 1.198E+05 | 10.31 | 48.74 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1155E-01
Intercept = 5.8244E+05

Least-squares line for q = a*delta-T^b
a = 2.0955E+04
b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVHTS

NOTE: 15 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVNT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0922
Alpha (based on Nusselt (Tdel)) = 0.8215
Enhancement (q) = .878
Enhancement (Del-T) = .907

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.038E+03 | 1.269E+04 | 1.244E+05 | 9.31 | 48.66 |
| 2 | 3.19 | 4.901E+03 | 1.307E+04 | 1.206E+05 | 9.23 | 48.70 |
| 3 | 2.74 | 4.702E+03 | 1.334E+04 | 1.155E+05 | 8.66 | 48.76 |
| 4 | 2.52 | 4.581E+03 | 1.346E+04 | 1.122E+05 | 8.34 | 48.74 |
| 5 | 2.30 | 4.450E+03 | 1.363E+04 | 1.089E+05 | 7.99 | 48.77 |
| 6 | 2.08 | 4.267E+03 | 1.348E+04 | 1.045E+05 | 7.75 | 48.82 |
| 7 | 1.86 | 4.081E+03 | 1.353E+04 | 1.003E+05 | 7.41 | 48.66 |
| 8 | 1.42 | 3.698E+03 | 1.447E+04 | 9.028E+04 | 6.24 | 48.65 |
| 9 | 0.97 | 3.076E+03 | 1.429E+04 | 7.465E+04 | 5.23 | 48.70 |
| 10 | 1.86 | 4.119E+03 | 1.396E+04 | 1.015E+05 | 7.27 | 48.70 |
| 11 | 2.75 | 4.739E+03 | 1.367E+04 | 1.178E+05 | 8.61 | 48.79 |
| 12 | 3.63 | 5.059E+03 | 1.283E+04 | 1.258E+05 | 9.61 | 48.74 |

Least-Squares Line for Ho vs q curve:
Slope = -2.5424E-01
Intercept = 5.7915E+05

Least-squares line for q = a*delta-T^b
a = 2.2680E+04
b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVNT2

NOTE: 12 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVNT3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0775
Alpha (based on Nusselt (Tdel)) = 0.7876
Enhancement (q) = .630
Enhancement (Del-T) = .869

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 4.954E+03 | 1.235E+04 | 1.248E+05 | 10.11 | 48.67 |
| 2 | 3.19 | 4.794E+03 | 1.255E+04 | 1.204E+05 | 9.59 | 48.64 |
| 3 | 2.75 | 4.586E+03 | 1.271E+04 | 1.152E+05 | 9.07 | 48.66 |
| 4 | 2.30 | 4.325E+03 | 1.284E+04 | 1.086E+05 | 8.46 | 48.73 |
| 5 | 1.86 | 3.990E+03 | 1.291E+04 | 9.969E+04 | 7.72 | 48.70 |
| 6 | 1.42 | 3.629E+03 | 1.394E+04 | 8.986E+04 | 6.45 | 48.63 |
| 7 | 0.97 | 3.079E+03 | 1.508E+04 | 7.590E+04 | 5.03 | 48.74 |
| 8 | 1.42 | 3.643E+03 | 1.416E+04 | 9.041E+04 | 6.39 | 48.62 |
| 9 | 0.97 | 3.061E+03 | 1.464E+04 | 7.506E+04 | 5.13 | 48.63 |
| 10 | 2.30 | 4.305E+03 | 1.268E+04 | 1.080E+05 | 8.51 | 48.50 |
| 11 | 2.75 | 4.555E+03 | 1.248E+04 | 1.146E+05 | 9.18 | 48.67 |
| 12 | 3.19 | 4.767E+03 | 1.237E+04 | 1.200E+05 | 9.70 | 48.69 |
| 13 | 3.63 | 4.946E-03 | 1.229E+04 | 1.245E+05 | 10.13 | 48.73 |
| 14 | 3.19 | 4.768E-03 | 1.237E+04 | 1.193E+05 | 9.65 | 48.67 |
| 15 | 3.63 | 4.977E+03 | 1.248E+04 | 1.248E+05 | 10.00 | 48.71 |
| 16 | 2.75 | 4.568E+03 | 1.255E+04 | 1.140E+05 | 9.09 | 48.73 |
| 17 | 2.30 | 4.322E+03 | 1.278E+04 | 1.072E+05 | 8.36 | 48.62 |
| 18 | 1.86 | 3.981E+03 | 1.278E+04 | 9.859E+04 | 7.72 | 48.71 |
| 19 | 1.42 | 3.636E-03 | 1.397E+04 | 8.922E+04 | 6.39 | 48.67 |
| 20 | 0.97 | 3.062E+03 | 1.455E+04 | 7.448E+04 | 5.12 | 48.70 |

Least-Squares Line for Ho vs q curve:
Slope = -2.8863E-01
Intercept = 5.8155E+05

Least-squares line for q = a*delta-T^b
a = 2.1947E+04
b = 7.5000E-01

NOTE: 20 data points were stored in file FONMVNT3



NOTE: 20 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMVNT4
      This analysis includes end-fin effect
      Thermal conductivity       =  21.0 (W/m.K)
      Inside diameter, Di        = 13.86 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  1.0742
Alpha (based on Nusselt (Tdel)) =  0.8455
Enhancement (q)                    =   .912
Enhancement (Del-T)                =   .933
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.095E+03 | 1.328E+04 | 1.274E+05 | 9.59 | 48.68 |
| 2 | 3.19 | 4.910E+03 | 1.340E+04 | 1.222E+05 | 9.12 | 48.63 |
| 3 | 2.75 | 4.749E+03 | 1.407E+04 | 1.183E+05 | 8.41 | 48.66 |
| 4 | 2.30 | 4.459E+03 | 1.413E+04 | 1.110E+05 | 7.86 | 48.66 |
| 5 | 1.86 | 4.166E+03 | 1.502E+04 | 1.037E+05 | 6.91 | 48.70 |
| 6 | 1.42 | 3.726E+03 | 1.559E+04 | 9.234E+04 | 5.92 | 48.67 |
| 7 | 0.97 | 3.166E+03 | 1.764E+04 | 7.792E+04 | 4.42 | 48.72 |
| 8 | 1.42 | 3.719E+03 | 1.550E+04 | 9.256E+04 | 5.97 | 48.67 |
| 9 | 0.97 | 3.161E+03 | 1.747E+04 | 7.765E+04 | 4.45 | 48.55 |
| 10 | 1.86 | 4.133E+03 | 1.464E+04 | 1.037E+05 | 7.09 | 48.70 |
| 11 | 2.30 | 4.476E+03 | 1.435E+04 | 1.125E+05 | 7.34 | 48.72 |
| 12 | 2.75 | 4.699E+03 | 1.366E+04 | 1.180E-05 | 8.63 | 48.58 |
| 13 | 3.19 | 4.914E-03 | 1.345E+04 | 1.234E+05 | 9.19 | 48.65 |
| 14 | 3.63 | 5.100E-03 | 1.333E+04 | 1.279E+05 | 9.60 | 48.66 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.9438E-01
  Intercept   =  5.8472E+05

Least-squares line for q = a*delta-T^b
  a =  2.4011E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMVNT4

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVNT5
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.1127
Alpha (based on Nusselt (Tdel)) = 0.8274
Enhancement (q) = .886
Enhancement (Del-T) = .913

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.64 | 5.029E+03 | 1.251E+04 | 1.289E+05 | 10.30 | 48.70 |
| 2 | 3.19 | 4.895E+03 | 1.291E+04 | 1.255E+05 | 9.72 | 48.73 |
| 3 | 2.75 | 4.735E+03 | 1.346E+04 | 1.209E+05 | 8.98 | 48.68 |
| 4 | 2.31 | 4.454E+03 | 1.353E+04 | 1.143E+05 | 8.45 | 48.73 |
| 5 | 1.86 | 4.116E+03 | 1.371E+04 | 1.054E+05 | 7.69 | 48.67 |
| 6 | 1.42 | 3.746E+03 | 1.490E+04 | 9.534E+04 | 6.40 | 48.68 |
| 7 | 0.97 | 3.160E+03 | 1.629E+04 | 7.999E+04 | 4.91 | 48.64 |
| 8 | 1.42 | 3.742E+03 | 1.490E+04 | 9.590E+04 | 6.44 | 48.70 |
| 9 | 0.97 | 3.180E+03 | 1.631E+04 | 8.016E+04 | 4.92 | 48.64 |
| 10 | 1.86 | 4.146E+03 | 1.408E+04 | 1.071E+05 | 7.60 | 48.71 |
| 11 | 2.31 | 4.489E+03 | 1.389E+04 | 1.159E+05 | 8.34 | 48.65 |
| 12 | 2.75 | 4.705E+03 | 1.327E+04 | 1.220E+05 | 9.19 | 48.72 |
| 13 | 3.19 | 4.894E+03 | 1.293E+04 | 1.266E+05 | 9.79 | 48.66 |
| 14 | 3.64 | 5.053E+03 | 1.269E+04 | 1.307E+05 | 10.20 | 48.64 |
| 15 | 2.31 | 4.487E+03 | 1.386E+04 | 1.151E+05 | 8.31 | 48.62 |
| 16 | 0.97 | 3.194E+03 | 1.662E+04 | 8.039E+04 | 4.94 | 48.76 |
| 17 | 3.64 | 5.059E+03 | 1.274E+04 | 1.312E+05 | 10.30 | 48.63 |

Least-Squares Line for Ho vs q curve:
Slope = -3.0266E-01
Intercept = 5.8489E+05

Least-squares line for q = a*delta-T^b
a = 2.2349E+04
b = 7.5000E-01

NOTE: 17 data points were stored in file FONMVNT5

NOTE: 17 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMAHIT1
      This analysis includes end-fin effect
      Thermal conductivity       =  21.0 (W/m.K)
      Inside diameter, Di        = 13.86 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.0225
Alpha (based on Nusselt (Tdel)) =  0.7981
Enhancement (q)                   =  1.047
Enhancement (Del-T)               =  1.035
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.62 | 5.446E+03 | 1.036E+04 | 3.985E-05 | 38.45 | 99.98 |
| 2 | 3.18 | 5.361E+03 | 1.049E+04 | 3.896E+05 | 37.14 | 99.95 |
| 3 | 2.73 | 5.268E+03 | 1.071E+04 | 3.914E+05 | 35.61 | 100.01 |
| 4 | 2.29 | 5.071E+03 | 1.069E+04 | 3.654E+05 | 34.19 | 99.93 |
| 5 | 1.85 | 4.858E+03 | 1.087E+04 | 3.496E+05 | 32.17 | 100.01 |
| 6 | 1.41 | 4.568E+03 | 1.119E+04 | 3.269E+05 | 29.22 | 99.89 |
| 7 | 0.97 | 4.150E+03 | 1.200E+04 | 2.957E+05 | 24.53 | 99.94 |
| 8 | 1.41 | 4.565E+03 | 1.119E+04 | 3.273E+05 | 29.29 | 99.95 |
| 9 | 0.97 | 4.147E+03 | 1.197E+04 | 2.955E+05 | 24.68 | 99.99 |
| 10 | 1.85 | 4.863E+03 | 1.090E+04 | 3.513E+05 | 32.21 | 100.05 |
| 11 | 2.29 | 5.073E+03 | 1.070E+04 | 3.670E+05 | 34.29 | 100.05 |
| 12 | 2.73 | 5.252E+03 | 1.069E+04 | 3.805E+05 | 35.60 | 99.97 |
| 13 | 3.17 | 5.373E+03 | 1.052E+04 | 3.889E+05 | 36.95 | 99.99 |
| 14 | 3.61 | 5.467E+03 | 1.041E+04 | 3.958E+05 | 39.00 | 100.02 |

```
Least-Squares Line for Ho vs q curve:
  Slope      = -2.8216E-01
  Intercept  =  7.7250E+05

Least-squares line for q = a*delta-T^b
  a =  2.6057E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMAHIT1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN1T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.1307
Alpha (based on Nusselt (Tdel)) = 0.7825
Enhancement (q) = 1.030
Enhancement (Del-T) = 1.022

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.61 | 4.807E+03 | 1.077E+04 | 3.467E+05 | 32.19 | 99.91 |
| 2 | 3.17 | 4.688E+03 | 1.104E+04 | 3.395E+05 | 30.76 | 99.99 |
| 3 | 2.73 | 4.497E+03 | 1.111E+04 | 3.257E+05 | 29.32 | 99.97 |
| 4 | 2.29 | 4.284E+03 | 1.133E+04 | 3.101E+05 | 27.36 | 99.93 |
| 5 | 1.85 | 3.979E+03 | 1.140E+04 | 2.883E+05 | 25.30 | 99.95 |
| 6 | 1.41 | 3.606E+03 | 1.170E+04 | 2.607E+05 | 22.28 | 99.95 |
| 7 | 0.97 | 3.138E+03 | 1.305E+04 | 2.259E+05 | 17.31 | 99.93 |
| 8 | 1.41 | 3.597E+03 | 1.165E+04 | 2.614E+05 | 22.43 | 99.99 |
| 9 | 0.97 | 3.150E+03 | 1.329E+04 | 2.272E+05 | 17.09 | 99.94 |
| 10 | 1.85 | 3.970E+03 | 1.141E+04 | 2.903E+05 | 25.44 | 99.93 |
| 11 | 2.29 | 4.261E+03 | 1.126E+04 | 3.122E+05 | 27.73 | 100.01 |
| 12 | 2.74 | 4.491E+03 | 1.115E+04 | 3.296E+05 | 29.55 | 99.99 |
| 13 | 3.18 | 4.650E+03 | 1.090E+04 | 3.412E+05 | 31.31 | 99.99 |
| 14 | 3.62 | 4.789E+03 | 1.075E+04 | 3.516E+05 | 32.71 | 100.05 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4626E-01
Intercept = 7.6014E+05

Least-squares line for q = a*delta-T b
a = 2.5679E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN1T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVH1T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.8918
Alpha (based on Nusselt (Tdel)) = 0.8018
Enhancement (q) = 1.061
Enhancement (Del-T) = 1.045

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.745E+03 | 1.196E+04 | 1.383E+05 | 11.56 | 48.65 |
| 2 | 3.19 | 5.661E+03 | 1.225E+04 | 1.364E+05 | 11.14 | 48.72 |
| 3 | 2.74 | 5.516E+03 | 1.244E+04 | 1.321E+05 | 10.62 | 48.65 |
| 4 | 2.30 | 5.291E+03 | 1.248E+04 | 1.269E+05 | 10.18 | 48.74 |
| 5 | 1.86 | 5.007E+03 | 1.256E+04 | 1.192E+05 | 9.49 | 48.65 |
| 6 | 1.41 | 4.660E+03 | 1.297E+04 | 1.105E+05 | 8.52 | 48.72 |
| 7 | 0.97 | 4.147E+03 | 1.379E+04 | 9.748E+04 | 7.07 | 48.58 |
| 8 | 1.41 | 4.655E+03 | 1.295E+04 | 1.107E+05 | 8.55 | 48.65 |
| 9 | 0.97 | 4.161E+03 | 1.396E+04 | 9.767E+04 | 6.99 | 48.59 |
| 10 | 1.86 | 5.005E+03 | 1.257E+04 | 1.203E+05 | 9.58 | 48.69 |
| 11 | 2.30 | 5.254E+03 | 1.228E+04 | 1.266E+05 | 10.31 | 48.73 |
| 12 | 2.74 | 5.500E+03 | 1.236E+04 | 1.321E+05 | 10.68 | 48.71 |
| 13 | 3.19 | 5.641E+03 | 1.215E+04 | 1.352E+05 | 11.13 | 48.69 |
| 14 | 3.63 | 5.740E+03 | 1.192E+04 | 1.365E+05 | 11.45 | 48.66 |

Least-Squares Line for Ho vs q curve:
Slope = -3.0415E-01
Intercept = 5.8381E+05

Least-squares line for q = a*delta-T^b
a = 2.2233E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH1T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMVN1T1
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.86 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  1.0235
Alpha (based on Nusselt (Tdel)) =  0.8381
Enhancement (q)                  =  1.029
Enhancement (Del-T)              =  1.021
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.036E+03 | 1.333E+04 | 1.191E+05 | 8.93 | 48.64 |
| 2 | 3.18 | 4.903E+03 | 1.385E+04 | 1.147E+05 | 8.28 | 48.70 |
| 3 | 2.74 | 4.718E+03 | 1.437E+04 | 1.093E+05 | 7.61 | 48.74 |
| 4 | 2.30 | 4.410E+03 | 1.427E+04 | 1.012E+05 | 7.09 | 48.71 |
| 5 | 1.85 | 4.088E+03 | 1.479E+04 | 9.300E+04 | 6.29 | 48.71 |
| 6 | 1.41 | 3.653E+03 | 1.550E+04 | 8.244E+04 | 5.32 | 48.68 |
| 7 | 0.97 | 3.071E+03 | 1.645E+04 | 6.840E+04 | 4.16 | 48.68 |
| 8 | 1.41 | 3.655E+03 | 1.542E+04 | 8.279E+04 | 5.37 | 48.68 |
| 9 | 0.97 | 3.074E+03 | 1.552E+04 | 6.840E+04 | 4.14 | 48.65 |
| 10 | 1.85 | 4.083E+03 | 1.475E+04 | 9.302E+04 | 6.31 | 48.63 |
| 11 | 2.30 | 4.405E+03 | 1.422E+04 | 1.012E+05 | 7.11 | 48.67 |
| 12 | 2.74 | 4.729E+03 | 1.444E+04 | 1.084E+05 | 7.50 | 48.65 |
| 13 | 3.18 | 4.906E+03 | 1.381E+04 | 1.125E+05 | 8.14 | 48.70 |
| 14 | 3.62 | 5.058E+03 | 1.340E+04 | 1.160E+05 | 8.66 | 48.72 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.5701E-01
  Intercept   =  5.3022E+05

Least-squares line for q = a*delta-T^b
  a =  2.3428E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMVN1T1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAH2T3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4479
Alpha (based on Nusselt (Tdel)) = 0.8064
Enhancement (q) = 1.062
Enhancement (Del-T) = 1.046

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.60 | 5.719E+03 | 1.054E+04 | 3.982E+05 | 37.78 | 99.95 |
| 2 | 3.16 | 5.593E+03 | 1.047E+04 | 3.876E+05 | 37.02 | 99.99 |
| 3 | 2.72 | 5.523E+03 | 1.072E+04 | 3.857E+05 | 35.98 | 100.00 |
| 4 | 2.28 | 5.382E+03 | 1.086E+04 | 3.767E+05 | 34.70 | 100.03 |
| 5 | 1.85 | 5.151E+03 | 1.087E+04 | 3.612E+05 | 33.23 | 100.01 |
| 6 | 1.41 | 4.895E+03 | 1.121E+04 | 3.426E+05 | 30.58 | 100.00 |
| 7 | 0.97 | 4.499E+03 | 1.186E+04 | 3.130E+05 | 26.39 | 99.99 |
| 8 | 1.41 | 4.867E+03 | 1.109E+04 | 3.429E+05 | 30.91 | 100.01 |
| 9 | 0.97 | 4.492E+03 | 1.183E+04 | 3.132E+05 | 26.48 | 99.95 |
| 10 | 1.85 | 5.139E+03 | 1.086E+04 | 3.649E+05 | 33.60 | 100.02 |
| 11 | 2.29 | 5.362E+03 | 1.083E+04 | 3.821E+05 | 35.28 | 99.97 |
| 12 | 2.73 | 5.487E+03 | 1.064E+04 | 3.919E+05 | 36.84 | 100.00 |
| 13 | 3.17 | 5.582E+03 | 1.049E+04 | 3.990E+05 | 38.02 | 99.99 |
| 14 | 3.61 | 5.706E+03 | 1.054E+04 | 4.078E+05 | 38.57 | 99.95 |

Least-Squares Line for Ho vs q curve:
Slope = -2.9602E-01
Intercept = 7.7502E+05

Least-squares line for q = a*delta-T^b
a = 2.5283E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH2T3

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0949
Alpha (based on Nusselt (Tdel)) = 0.8014
Enhancement (q) = 1.063
Enhancement (Del-T) = 1.047

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 0.97 | 3.104E+03 | 1.352E+04 | 2.237E+05 | 16.55 | 100.04 |
| 2 | 1.41 | 3.591E+03 | 1.217E+04 | 2.597E+05 | 21.33 | 99.99 |
| 3 | 1.85 | 3.987E+03 | 1.191E+04 | 2.876E+05 | 24.14 | 99.99 |
| 4 | 2.29 | 4.290E+03 | 1.175E+04 | 3.092E+05 | 26.32 | 99.95 |
| 5 | 2.73 | 4.512E+03 | 1.149E+04 | 3.242E+05 | 28.21 | 99.94 |
| 6 | 3.17 | 4.716E+03 | 1.145E+04 | 3.387E+05 | 29.60 | 100.01 |
| 7 | 3.61 | 4.853E+03 | 1.122E+04 | 3.475E+05 | 30.97 | 99.99 |
| 8 | 3.17 | 4.734E+03 | 1.151E+04 | 3.376E+05 | 29.32 | 99.97 |
| 9 | 3.61 | 4.873E+03 | 1.131E+04 | 3.477E+05 | 30.73 | 99.94 |
| 10 | 2.73 | 4.531E+03 | 1.154E+04 | 3.218E+05 | 27.89 | 99.93 |
| 11 | 2.29 | 4.298E+03 | 1.168E+04 | 3.047E+05 | 26.09 | 99.94 |
| 12 | 1.85 | 3.969E+03 | 1.159E+04 | 2.813E+05 | 24.26 | 99.95 |
| 13 | 1.41 | 3.602E+03 | 1.201E+04 | 2.543E+05 | 21.18 | 99.95 |
| 14 | 0.97 | 3.164E+03 | 1.413E+04 | 2.225E+05 | 15.75 | 100.07 |

Least-Squares Line for Ho vs q curve:
Slope = -2.3609E-01
Intercept = 7.5845E-05

Least-squares line for q = a*delta-T^b
a = 2.6571E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN2T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMVH2T1
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.86 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.0049
Alpha (based on Nusselt (Tdel)) =  0.7965
Enhancement (q)                   =  1.052
Enhancement (Del-T)               =  1.038
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.64 | 5.753E+03 | 1.174E+04 | 1.466E+05 | 12.49 | 48.73 |
| 2 | 3.19 | 5.631E+03 | 1.181E+04 | 1.423E+05 | 12.04 | 48.69 |
| 3 | 2.75 | 5.462E+03 | 1.182E+04 | 1.363E+05 | 11.53 | 48.63 |
| 4 | 2.52 | 5.369E+03 | 1.186E+04 | 1.341E+05 | 11.31 | 48.80 |
| 5 | 2.30 | 5.263E+03 | 1.190E+04 | 1.315E+05 | 11.05 | 48.85 |
| 6 | 1.86 | 4.949E+03 | 1.172E+04 | 1.226E+05 | 10.46 | 48.70 |
| 7 | 1.42 | 4.621E+03 | 1.203E+04 | 1.132E+05 | 9.41 | 48.63 |
| 8 | 0.97 | 4.146E+03 | 1.277E+04 | 1.014E+05 | 7.94 | 48.80 |
| 9 | 0.97 | 4.229E+03 | 1.364E+04 | 1.035E+05 | 7.58 | 48.54 |
| 10 | 1.42 | 4.657E+03 | 1.230E+04 | 1.153E+05 | 9.37 | 48.65 |
| 11 | 1.86 | 5.011E+03 | 1.209E+04 | 1.247E+05 | 10.32 | 48.65 |
| 12 | 2.30 | 5.284E+03 | 1.203E+04 | 1.321E+05 | 10.98 | 48.66 |
| 13 | 2.53 | 5.348E+03 | 1.177E+04 | 1.341E+05 | 11.39 | 48.74 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.9344E-01
  Intercept  =  5.8163E+05

Least-squares line for q = a*delta-T^b
  a =  2.1707E+04
  b =  7.5000E-01


NOTE: 13 data points were stored in file FONMVH2T1

NOTE: 13 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMVH2T2
      This analysis includes end-fin effect
      Thermal conductivity       =  21.0 (W/m.K)
      Inside diameter, Di        = 13.86 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  1.9482
Alpha (based on Nusselt (Tdel)) =  0.7873
Enhancement (q)                  =  1.035
Enhancement (Del-T)              =  1.026
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.64 | 5.614E+03 | 1.134E+04 | 1.454E+05 | 12.92 | 48.64 |
| 2 | 3.19 | 5.552E+03 | 1.166E+04 | 1.425E+05 | 12.23 | 48.64 |
| 3 | 2.75 | 5.383E+03 | 1.168E+04 | 1.380E+05 | 11.82 | 48.75 |
| 4 | 2.53 | 5.288E+03 | 1.171E+04 | 1.348E+05 | 11.51 | 48.67 |
| 5 | 2.31 | 5.193E+03 | 1.181E+04 | 1.326E+05 | 11.22 | 48.77 |
| 6 | 1.86 | 4.952E+03 | 1.205E+04 | 1.263E+05 | 10.48 | 48.91 |
| 7 | 1.42 | 4.573E+03 | 1.213E+04 | 1.155E+05 | 9.52 | 48.68 |
| 8 | 0.97 | 4.107E+03 | 1.303E+04 | 1.024E+05 | 7.86 | 48.71 |
| 9 | 1.42 | 4.582E+03 | 1.219E+04 | 1.156E+05 | 9.49 | 48.70 |
| 10 | 0.97 | 4.121E+03 | 1.316E+04 | 1.025E+05 | 7.79 | 48.69 |
| 11 | 2.31 | 5.164E+03 | 1.167E+04 | 1.316E+05 | 11.28 | 48.66 |
| 12 | 3.64 | 5.630E+03 | 1.139E+04 | 1.443E+05 | 12.67 | 48.65 |
| 13 | 3.19 | 5.480E+03 | 1.134E+04 | 1.398E+05 | 12.33 | 48.58 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -3.2945E-01
  Intercept   =  5.8591E+05

Least-squares line for q = a*delta-T^b
  a =  2.1568E+04
  b =  7.5000E-01


NOTE: 13 data points were stored in file FONMVH2T2

NOTE: 13 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVH2T3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2400
Alpha (based on Nusselt (Tdel)) = 0.7662
Enhancement (q) = .999
Enhancement (Del-T) = .999

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.823E+03 | 1.143E+04 | 1.395E+05 | 12.20 | 48.63 |
| 2 | 3.18 | 5.684E+03 | 1.138E+04 | 1.353E+05 | 11.89 | 48.64 |
| 3 | 2.74 | 5.568E+03 | 1.155E+04 | 1.320E+05 | 11.43 | 48.63 |
| 4 | 2.30 | 5.354E+03 | 1.149E+04 | 1.267E+05 | 11.02 | 48.64 |
| 5 | 1.86 | 5.135E+03 | 1.170E+04 | 1.209E+05 | 10.33 | 48.65 |
| 6 | 1.41 | 4.825E+03 | 1.201E+04 | 1.132E+05 | 9.43 | 48.70 |
| 7 | 0.97 | 4.405E+03 | 1.300E+04 | 1.015E+05 | 7.81 | 48.71 |
| 8 | 1.41 | 4.827E+03 | 1.203E+04 | 1.138E+05 | 9.46 | 48.67 |
| 9 | 0.97 | 4.383E+03 | 1.282E+04 | 1.015E+05 | 7.92 | 48.72 |
| 10 | 1.86 | 5.126E+03 | 1.167E+04 | 1.223E+05 | 10.48 | 48.74 |
| 11 | 2.30 | 5.341E+03 | 1.145E+04 | 1.275E+05 | 11.14 | 48.62 |
| 12 | 2.74 | 5.553E+03 | 1.150E+04 | 1.334E+05 | 11.60 | 48.70 |
| 13 | 3.19 | 5.669E+03 | 1.133E+04 | 1.358E+05 | 11.99 | 48.61 |
| 14 | 3.63 | 5.802E+03 | 1.135E+04 | 1.400E+05 | 12.33 | 48.74 |

Least-Squares Line for Ho vs q curve:
Slope = -3.3576E-01
Intercept = 5.8581E+05

Least-squares line for q = a*delta-T^b
a = 2.1177E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH2T3

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVN2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 0.9979
Alpha (based on Nusselt (Tdel)) = 0.8181
Enhancement (q) = .996
Enhancement (Del-T) = .997

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 0.97 | 2.991E+03 | 1.622E+04 | 7.061E+04 | 4.35 | 48.71 |
| 2 | 1.41 | 3.543E+03 | 1.476E+04 | 8.456E+04 | 5.73 | 48.66 |
| 3 | 1.86 | 3.947E+03 | 1.394E+04 | 9.451E+04 | 6.79 | 48.66 |
| 4 | 2.30 | 4.306E+03 | 1.392E+04 | 1.032E+05 | 7.42 | 48.65 |
| 5 | 2.74 | 4.548E+03 | 1.342E+04 | 1.088E+05 | 8.10 | 48.67 |
| 6 | 2.74 | 4.582E+03 | 1.372E+04 | 1.092E+05 | 7.96 | 48.63 |
| 7 | 3.18 | 4.765E+03 | 1.322E+04 | 1.138E+05 | 8.61 | 48.69 |
| 8 | 3.63 | 5.009E+03 | 1.350E+04 | 1.194E+05 | 8.85 | 48.68 |
| 9 | 3.18 | 4.784E+03 | 1.334E+04 | 1.135E+05 | 8.51 | 48.66 |
| 10 | 3.63 | 4.978E+03 | 1.325E+04 | 1.182E+05 | 8.92 | 48.70 |
| 11 | 2.74 | 4.556E+03 | 1.345E+04 | 1.078E+05 | 8.02 | 48.72 |
| 12 | 2.30 | 4.311E+03 | 1.389E+04 | 1.016E+05 | 7.31 | 48.68 |
| 13 | 1.86 | 3.971E+03 | 1.413E+04 | 9.320E+04 | 6.59 | 48.70 |
| 14 | 1.41 | 3.548E+03 | 1.465E+04 | 8.254E+04 | 5.63 | 48.66 |
| 15 | 0.97 | 2.987E+03 | 1.585E+04 | 6.885E+04 | 4.34 | 48.71 |

Least-Squares Line for Ho vs q curve:
Slope = -2.6538E-01
Intercept = 5.8038E+05

Least-squares line for q = a*delta-T^b
a = 2.2839E+04
b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVN2T1

NOTE: 15 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVN3T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 0.9111
Alpha (based on Nusselt (Tdel)) = 0.6359
Enhancement (q) = .624
Enhancement (Del-T) = .702

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.64 | 4.261E+03 | 9.903E+03 | 1.078E+05 | 10.89 | 48.61 |
| 2 | 3.19 | 4.046E+03 | 9.629E+03 | 1.034E+05 | 10.73 | 48.86 |
| 3 | 2.75 | 3.864E+03 | 9.694E+03 | 9.833E+04 | 10.14 | 48.76 |
| 4 | 2.30 | 3.695E+03 | 1.016E+04 | 9.272E+04 | 9.13 | 48.43 |
| 5 | 1.86 | 3.435E+03 | 1.049E+04 | 8.615E+04 | 8.22 | 48.48 |
| 6 | 0.97 | 2.619E+03 | 1.170E+04 | 6.453E+04 | 5.52 | 48.49 |
| 7 | 1.42 | 3.070E+03 | 1.067E+04 | 7.722E+04 | 7.24 | 48.63 |
| 8 | 0.97 | 2.649E+03 | 1.238E+04 | 6.524E+04 | 5.27 | 48.32 |
| 9 | 1.42 | 3.072E+03 | 1.072E+04 | 7.736E+04 | 7.22 | 48.54 |
| 10 | 1.86 | 3.352E+03 | 9.765E+03 | 8.670E+04 | 8.88 | 49.08 |
| 11 | 2.31 | 3.716E+03 | 1.034E+04 | 9.406E+04 | 9.10 | 48.44 |
| 12 | 2.75 | 3.859E+03 | 9.681E+03 | 9.967E+04 | 10.30 | 48.92 |
| 13 | 3.19 | 4.091E+03 | 9.905E+03 | 1.040E+05 | 10.50 | 48.50 |
| 14 | 3.64 | 4.275E+03 | 9.995E+03 | 1.085E+05 | 10.36 | 48.49 |

Least-Squares Line for Ho vs q curve:
Slope = -3.4927E-01
Intercept = 5.8044E+05

Least-squares line for q = a*delta-T^b
a = 1.7709E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN3T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by              : O'KEEFE
      This analysis done on file : FONMAH3T1
      This analysis includes end-fin effect
      Thermal conductivity      =  21.0 (W/m.K)
      Inside diameter, Di       = 13.86 (mm)
      Outside diameter, Do      = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  2.1377
Alpha (based on Nusselt (Tdel)) =  0.7239
Enhancement (q)                  =   .872
Enhancement (Del-T)              =   .902
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.62 | 5.173E+03 | 9.249E+03 | 3.780E+05 | 40.88 | 99.86 |
| 2 | 3.18 | 5.068E+03 | 9.251E+03 | 3.717E+05 | 40.18 | 100.01 |
| 3 | 2.74 | 4.950E+03 | 9.289E+03 | 3.634E+05 | 39.12 | 100.09 |
| 4 | 2.30 | 4.830E+03 | 9.456E+03 | 3.538E+05 | 37.41 | 99.96 |
| 5 | 1.85 | 4.616E+03 | 9.475E+03 | 3.377E+05 | 35.64 | 99.91 |
| 6 | 1.41 | 4.409E+03 | 9.947E+03 | 3.229E+05 | 32.46 | 100.11 |
| 7 | 0.97 | 4.014E+03 | 1.042E+04 | 2.923E+05 | 28.06 | 100.13 |
| 8 | 1.41 | 4.374E+03 | 9.784E+03 | 3.200E+05 | 32.70 | 99.81 |
| 9 | 0.97 | 4.028E+03 | 1.051E+04 | 2.924E+05 | 27.81 | 99.90 |
| 10 | 1.85 | 4.619E+03 | 9.508E+03 | 3.400E+05 | 35.76 | 99.92 |
| 11 | 2.30 | 4.790E+03 | 9.328E+03 | 3.539E+05 | 37.95 | 99.88 |
| 12 | 2.74 | 4.971E+03 | 9.385E+03 | 3.665E+05 | 39.05 | 99.75 |
| 13 | 3.18 | 5.054E+03 | 9.224E+03 | 3.749E+05 | 40.65 | 100.17 |
| 14 | 3.62 | 5.149E+03 | 9.135E+03 | 3.821E+05 | 41.56 | 100.15 |

```
Least-Squares Line for Ho vs q curve:
  Slope      = -3.3392E-01
  Intercept  =  7.7974E+05

Least-squares line for q = a*delta-T b
  a =  2.3441E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMAH3T1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN3T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petuknov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0337
Alpha (based on Nusselt (Tdel)) = 0.6976
Enhancement (q) = .854
Enhancement (Del-T) = .888

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 4.380E+03 | 9.469E+03 | 3.271E+05 | 34.55 | 99.89 |
| 2 | 3.19 | 4.286E+03 | 9.764E+03 | 3.183E+05 | 32.60 | 99.60 |
| 3 | 2.74 | 4.068E+03 | 9.592E+03 | 3.044E+05 | 31.73 | 100.24 |
| 4 | 2.30 | 3.881E+03 | 9.813E+03 | 2.889E+05 | 29.44 | 99.97 |
| 5 | 1.86 | 3.576E+03 | 9.664E+03 | 2.665E+05 | 27.57 | 100.05 |
| 6 | 1.41 | 3.275E+03 | 1.023E+04 | 2.435E+05 | 23.79 | 99.97 |
| 7 | 0.97 | 2.867E+03 | 1.169E+04 | 2.120E+05 | 18.13 | 99.93 |
| 8 | 1.41 | 3.275E+03 | 1.025E+04 | 2.441E+05 | 23.81 | 99.99 |
| 9 | 0.97 | 2.863E+03 | 1.167E+04 | 2.123E+05 | 18.20 | 100.00 |
| 10 | 1.86 | 3.590E+03 | 9.795E+03 | 2.683E+05 | 27.40 | 100.01 |
| 11 | 2.30 | 3.860E+03 | 9.708E+03 | 2.889E+05 | 29.75 | 100.06 |
| 12 | 2.74 | 4.087E+03 | 9.713E+03 | 3.058E+05 | 31.49 | 100.00 |
| 13 | 3.19 | 4.250E+03 | 9.590E+03 | 3.179E+05 | 33.14 | 99.95 |
| 14 | 3.63 | 4.399E+03 | 9.560E+03 | 3.290E+05 | 34.42 | 99.97 |

Least-Squares Line for Ho vs q curve:
Slope = -2.8762E-01
Intercept = 7.6233E+05

Least-squares line for q = a*delta-T b
a = 2.2978E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVH3T2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.8658
Alpha (based on Nusselt (Tdel)) = 0.6182
Ennancement (q) = .638
Enhancement (Del-T) = .714

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 0.97 | 3.760E+03 | 1.046E+04 | 8.859E+04 | 8.47 | 48.70 |
| 2 | 1.41 | 4.094E+03 | 9.489E+03 | 9.805E+04 | 10.33 | 48.72 |
| 3 | 1.86 | 4.370E+03 | 9.286E+03 | 1.049E+05 | 11.30 | 48.67 |
| 4 | 2.30 | 4.582E+03 | 9.216E+03 | 1.114E+05 | 12.09 | 48.83 |
| 5 | 2.74 | 4.733E+03 | 9.123E+03 | 1.144E+05 | 12.54 | 48.70 |
| 6 | 3.19 | 4.798E+03 | 8.870E+03 | 1.165E+05 | 13.14 | 48.78 |
| 7 | 3.63 | 4.986E+03 | 9.127E+03 | 1.207E+05 | 13.23 | 48.71 |
| 8 | 3.19 | 4.835E+03 | 8.993E+03 | 1.174E+05 | 13.06 | 48.88 |
| 9 | 3.63 | 4.991E+03 | 9.142E+03 | 1.206E+05 | 13.19 | 48.70 |
| 10 | 2.74 | 4.753E+03 | 9.191E+03 | 1.142E+05 | 12.43 | 48.74 |
| 11 | 2.30 | 4.573E+03 | 9.156E+03 | 1.093E+05 | 11.92 | 48.72 |
| 12 | 1.86 | 4.391E+03 | 9.369E+03 | 1.040E+05 | 11.10 | 48.65 |
| 13 | 1.41 | 4.130E+03 | 9.662E+03 | 9.732E+04 | 10.07 | 48.58 |
| 14 | 0.97 | 3.751E+03 | 1.036E+04 | 8.735E+04 | 8.43 | 48.72 |

Least-Squares Line for Ho vs q curve:
Slope = -4.1572E-01
Intercept = 5.8640E+05

Least-squares line for q = a*delta-T^b
a = 1.7233E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH3T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAH4T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3785
Alpha (based on Nusselt (Tdel)) = 0.8528
Enhancement (q) = 1.144
Enhancement (Del-T) = 1.106

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.62 | 5.824E+03 | 1.114E+04 | 4.309E+05 | 38.69 | 99.98 |
| 2 | 3.18 | 5.742E+03 | 1.128E+04 | 4.235E+05 | 37.56 | 100.02 |
| 3 | 2.74 | 5.616E+03 | 1.136E+04 | 4.128E+05 | 36.34 | 99.96 |
| 4 | 2.30 | 5.449E+03 | 1.145E+04 | 3.989E+05 | 34.94 | 99.89 |
| 5 | 1.85 | 5.213E+03 | 1.152E+04 | 3.825E+05 | 33.19 | 100.07 |
| 6 | 1.41 | 4.921E+03 | 1.181E+04 | 3.593E+05 | 30.41 | 100.04 |
| 7 | 0.97 | 4.520E+03 | 1.273E+04 | 3.276E+05 | 25.72 | 99.95 |
| 8 | 1.41 | 4.901E+03 | 1.171E+04 | 3.586E+05 | 30.62 | 100.03 |
| 9 | 0.97 | 4.519E+03 | 1.272E+04 | 3.274E+05 | 25.74 | 99.97 |
| 10 | 1.85 | 5.226E+03 | 1.160E+04 | 3.838E+05 | 33.10 | 99.96 |
| 11 | 2.30 | 5.444E+03 | 1.144E+04 | 4.006E+05 | 35.01 | 100.00 |
| 12 | 2.74 | 5.614E+03 | 1.136E+04 | 4.135E+05 | 36.40 | 99.95 |
| 13 | 3.18 | 5.713E+03 | 1.116E+04 | 4.209E+05 | 37.71 | 99.98 |
| 14 | 3.62 | 5.810E+03 | 1.108E+04 | 4.290E+05 | 38.64 | 99.99 |

Least-Squares Line for Ho vs q curve:
Slope = -2.6757E-01
Intercept = 7.7418E+05

Least-squares line for q = a*delta-T^b
a = 2.7891E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH4T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN4T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.3768
Alpha (based on Nusselt (Tdel)) = 0.7912
Enhancement (q) = 1.045
Enhancement (Del-T) = 1.034

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.090E+03 | 1.092E+04 | 3.804E+05 | 34.85 | 99.98 |
| 2 | 3.18 | 4.936E+03 | 1.089E+04 | 3.658E+05 | 33.58 | 99.94 |
| 3 | 2.74 | 4.757E+03 | 1.092E+04 | 3.519E+05 | 32.20 | 99.99 |
| 4 | 2.30 | 4.522E+03 | 1.089E+04 | 3.336E+05 | 30.62 | 99.97 |
| 5 | 1.85 | 4.214E+03 | 1.078E+04 | 3.103E+05 | 28.79 | 99.95 |
| 6 | 1.41 | 3.872E+03 | 1.109E+04 | 2.848E+05 | 25.68 | 99.95 |
| 7 | 0.97 | 3.497E+03 | 1.310E+04 | 2.558E+05 | 19.52 | 100.00 |
| 8 | 1.41 | 3.864E+03 | 1.104E+04 | 2.849E+05 | 25.30 | 99.97 |
| 9 | 0.97 | 3.519E+03 | 1.343E+04 | 2.573E+05 | 19.15 | 99.91 |
| 10 | 1.86 | 4.211E+03 | 1.079E+04 | 3.114E+05 | 28.86 | 99.94 |
| 11 | 2.30 | 4.527E+03 | 1.094E+04 | 3.348E+05 | 30.61 | 99.95 |
| 12 | 2.74 | 4.751E+03 | 1.090E+04 | 3.513E+05 | 32.24 | 99.92 |
| 13 | 3.18 | 4.945E+03 | 1.093E+04 | 3.662E+05 | 33.50 | 99.97 |
| 14 | 3.62 | 5.101E+03 | 1.093E+04 | 3.776E+05 | 34.56 | 99.97 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4793E-01
Intercept = 7.6032E-05

Least-squares line for q = a*delta-T^b
a = 2.5008E-04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN4T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVH4T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0810
Alpha (based on Nusselt (Tdel)) = 0.8211
Enhancement (q) = 1.095
Enhancement (Del-T) = 1.071

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.967E+03 | 1.241E+04 | 1.468E+05 | 11.83 | 48.70 |
| 2 | 3.19 | 5.798E+03 | 1.229E+04 | 1.417E+05 | 11.52 | 48.70 |
| 3 | 2.74 | 5.668E+03 | 1.251E+04 | 1.380E+05 | 11.03 | 48.74 |
| 4 | 2.30 | 5.424E+03 | 1.239E+04 | 1.313E+05 | 10.59 | 48.70 |
| 5 | 1.86 | 5.192E+03 | 1.272E+04 | 1.252E+05 | 9.85 | 48.73 |
| 6 | 1.41 | 4.872E+03 | 1.326E+04 | 1.168E+05 | 8.81 | 48.74 |
| 7 | 0.97 | 4.393E+03 | 1.440E+04 | 1.038E+05 | 7.21 | 48.67 |
| 8 | 1.41 | 4.884E+03 | 1.337E+04 | 1.175E+05 | 8.79 | 48.67 |
| 9 | 0.97 | 4.402E+03 | 1.451E+04 | 1.044E+05 | 7.20 | 48.70 |
| 10 | 1.86 | 5.207E+03 | 1.282E+04 | 1.263E+05 | 9.95 | 48.72 |
| 11 | 2.30 | 5.449E+03 | 1.254E+04 | 1.327E+05 | 10.58 | 48.69 |
| 12 | 2.74 | 5.653E+03 | 1.244E+04 | 1.377E+05 | 11.07 | 48.69 |
| 13 | 3.19 | 5.793E+03 | 1.226E+04 | 1.407E+05 | 11.48 | 48.76 |
| 14 | 3.63 | 5.943E+03 | 1.229E+04 | 1.441E+05 | 11.73 | 48.70 |

Least-Squares Line for Ho vs q curve:
Slope = -3.1730E-01
Intercept = 5.8664E+05

Least-squares line for q = a*delta-T^b
a = 2.2845E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH4T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                  : O'KEEFE
      This analysis done on file : FONMVN4T1
      This analysis includes end-fin effect
      Thermal conductivity         =  21.0 (W/m.K)
      Inside diameter, Di          = 13.86 (mm)
      Outside diameter, Do         = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  1.1394
Alpha (based on Nusselt (Tdel)) =  0.8245
Enhancement (q)                   =  1.007
Enhancement (Del-T)               =  1.005
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.64 | 5.167E+03 | 1.309E+04 | 1.307E+05 | 9.99 | 48.71 |
| 2 | 3.19 | 4.973E+03 | 1.310E+04 | 1.248E+05 | 9.53 | 48.66 |
| 3 | 2.75 | 4.780E+03 | 1.339E+04 | 1.196E+05 | 8.93 | 48.68 |
| 4 | 2.30 | 4.490E+03 | 1.333E+04 | 1.121E+05 | 8.41 | 48.67 |
| 5 | 1.86 | 4.130E+03 | 1.322E+04 | 1.029E+05 | 7.79 | 48.70 |
| 6 | 1.42 | 3.722E+03 | 1.369E+04 | 9.235E+04 | 6.75 | 48.66 |
| 7 | 0.97 | 3.186E+03 | 1.500E+04 | 7.819E+04 | 5.21 | 48.70 |
| 8 | 1.42 | 3.727E+03 | 1.377E+04 | 9.296E+04 | 6.75 | 48.74 |
| 9 | 0.97 | 3.205E+03 | 1.544E+04 | 7.870E+04 | 5.10 | 48.70 |
| 10 | 1.86 | 4.125E+03 | 1.319E+04 | 1.032E+05 | 7.83 | 48.67 |
| 11 | 2.30 | 4.483E+03 | 1.330E+04 | 1.127E+05 | 8.47 | 48.67 |
| 12 | 2.75 | 4.737E+03 | 1.308E+04 | 1.197E+05 | 9.15 | 48.72 |
| 13 | 3.19 | 4.955E+03 | 1.299E+04 | 1.257E+05 | 9.68 | 48.74 |
| 14 | 3.64 | 5.165E+03 | 1.309E+04 | 1.311E+05 | 10.02 | 48.69 |
| 15 | 2.30 | 4.473E+03 | 1.321E+04 | 1.127E+05 | 8.53 | 48.72 |
| 16 | 0.97 | 3.210E+03 | 1.559E+04 | 7.913E+04 | 5.07 | 48.70 |
| 17 | 3.64 | 5.150E+03 | 1.301E+04 | 1.315E+05 | 10.11 | 48.71 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.6143E-01
  Intercept   =  5.7985E+05

Least-squares line for q = a*delta-T^b
  a =  2.2773E+04
  b =  7.5000E-01


NOTE: 17 data points were stored in file FONMVN4T1

NOTE. 17 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHST1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2507
Alpha (based on Nusselt (Tdel)) = 0.8691
Enhancement (q) = 1.173
Enhancement (Del-T) = 1.127

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.60 | 5.914E+03 | 1.155E+04 | 4.113E+05 | 35.61 | 99.96 |
| 2 | 3.16 | 5.820E+03 | 1.165E+04 | 4.011E+05 | 34.43 | 100.02 |
| 3 | 2.72 | 5.727E+03 | 1.189E+04 | 3.917E+05 | 32.93 | 100.03 |
| 4 | 2.28 | 5.544E+03 | 1.196E+04 | 3.769E+05 | 31.52 | 99.92 |
| 5 | 1.84 | 5.333E+03 | 1.220E+04 | 3.613E+05 | 29.62 | 100.03 |
| 6 | 1.40 | 5.012E+03 | 1.244E+04 | 3.367E+05 | 27.07 | 99.95 |
| 7 | 0.96 | 4.578E+03 | 1.333E+04 | 3.054E+05 | 22.91 | 99.99 |
| 8 | 1.40 | 5.013E+03 | 1.246E+04 | 3.375E+05 | 27.09 | 99.93 |
| 9 | 0.96 | 4.582E+03 | 1.335E+04 | 3.055E+05 | 22.88 | 100.02 |
| 10 | 1.84 | 5.323E+03 | 1.216E+04 | 3.607E+05 | 29.68 | 99.92 |
| 11 | 2.28 | 5.574E+03 | 1.209E+04 | 3.785E+05 | 31.30 | 99.97 |
| 12 | 2.72 | 5.745E+03 | 1.196E+04 | 3.907E+05 | 32.68 | 99.99 |
| 13 | 3.15 | 5.848E+03 | 1.173E+04 | 3.975E+05 | 33.88 | 99.96 |
| 14 | 3.59 | 5.979E+03 | 1.174E+04 | 4.064E+05 | 34.60 | 99.95 |
| 15 | 3.15 | 5.826E+03 | 1.154E+04 | 3.949E+05 | 33.93 | 99.99 |
| 16 | 3.59 | 5.992E+03 | 1.190E+04 | 4.066E+05 | 34.47 | 99.97 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4930E-01
Intercept = 7.6900E+05

Least-squares line for q = a*delta-T^b
a = 2.8492E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMAHST1

NOTE: 16 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMANST1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0988
Alpha (based on Nusselt (Tdel)) = 0.8367
Enhancement (q) = 1.126
Enhancement (Del-T) = 1.093

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.16 | 4.852E+03 | 1.203E+04 | 3.362E+05 | 27.95 | 99.95 |
| 2 | 2.72 | 4.685E+03 | 1.233E+04 | 3.227E+05 | 26.16 | 99.92 |
| 3 | 2.28 | 4.429E+03 | 1.238E+04 | 3.042E+05 | 24.57 | 100.01 |
| 4 | 1.84 | 4.108E+03 | 1.244E+04 | 2.809E+05 | 22.58 | 99.95 |
| 5 | 1.40 | 3.720E+03 | 1.286E+04 | 2.539E+05 | 19.74 | 100.04 |
| 6 | 0.96 | 3.248E+03 | 1.494E+04 | 2.203E+05 | 14.74 | 99.91 |
| 7 | 1.40 | 3.709E+03 | 1.279E+04 | 2.538E+05 | 19.85 | 99.92 |
| 8 | 0.96 | 3.235E+03 | 1.471E+04 | 2.200E+05 | 14.95 | 99.99 |
| 9 | 1.84 | 4.106E+03 | 1.249E+04 | 2.825E+05 | 22.63 | 99.95 |
| 10 | 2.28 | 4.423E+03 | 1.237E+04 | 3.052E+05 | 24.67 | 100.02 |
| 11 | 2.72 | 4.682E+03 | 1.232E+04 | 3.235E+05 | 26.26 | 100.03 |
| 12 | 3.61 | 5.010E+03 | 1.198E+04 | 3.534E+05 | 29.50 | 100.00 |
| 13 | 3.17 | 4.845E+03 | 1.219E+04 | 3.473E+05 | 28.49 | 99.93 |
| 14 | 3.61 | 5.004E+03 | 1.204E+04 | 3.592E+05 | 29.84 | 100.02 |

Least-Squares Line for Ho vs q curve:
Slope = -2.1506E-01
Intercept = 7.5527E+05

Least-squares line for q = a*delta-T^b
a = 2.7811E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANST1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVHST1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0139
Alpha (based on Nusselt (Tdel)) = 0.8415
Enhancement (q) = 1.132
Enhancement (Del-T) = 1.097

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 6.026E+03 | 1.281E+04 | 1.423E+05 | 11.11 | 48.66 |
| 2 | 3.18 | 5.928E+03 | 1.304E+04 | 1.376E+05 | 10.55 | 48.70 |
| 3 | 2.74 | 5.738E+03 | 1.301E+04 | 1.308E+05 | 10.05 | 48.61 |
| 4 | 2.30 | 5.558E+03 | 1.329E+04 | 1.254E+05 | 9.43 | 48.61 |
| 5 | 1.85 | 5.293E+03 | 1.354E+04 | 1.186E+05 | 8.76 | 48.71 |
| 6 | 1.41 | 4.928E+03 | 1.394E+04 | 1.093E+05 | 7.84 | 48.73 |
| 7 | 0.97 | 4.410E+03 | 1.497E+04 | 9.625E+04 | 6.43 | 48.70 |
| 8 | 1.41 | 4.910E+03 | 1.381E+04 | 1.091E+05 | 7.90 | 48.68 |
| 9 | 0.97 | 4.407E+03 | 1.493E+04 | 9.616E+04 | 6.44 | 48.71 |
| 10 | 1.85 | 5.301E+03 | 1.360E+04 | 1.188E+05 | 8.74 | 48.55 |
| 11 | 2.30 | 5.540E+03 | 1.318E+04 | 1.248E+05 | 9.47 | 48.58 |
| 12 | 2.74 | 5.772E+03 | 1.316E+04 | 1.302E+05 | 9.89 | 48.56 |
| 13 | 3.18 | 5.911E+03 | 1.292E+04 | 1.336E+05 | 10.34 | 48.72 |
| 14 | 3.62 | 6.113E+03 | 1.314E+04 | 1.371E+05 | 10.43 | 48.65 |
| 15 | 2.29 | 5.556E+03 | 1.325E+04 | 1.235E+05 | 9.32 | 48.73 |
| 16 | 3.62 | 6.097E+03 | 1.306E+04 | 1.364E+05 | 10.44 | 48.69 |

Least-Squares Line for Ho vs q curve:
Slope = -2.8741E-01
Intercept = 5.8357E-05

Least-squares line for q = a*delta-T^b
a = 2.3376E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVHST1

NOTE: 16 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                  : O'KEEFE
      This analysis done on file : FONMVNST1
      This analysis includes end-fin effect
      Thermal conductivity       =  21.0 (W/m.K)
      Inside diameter, Di        = 13.86 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)       =  0.9775
Alpha (based on Nusselt (Tdel)) =  0.8425
Enhancement (q)                    =  1.036
Enhancement (Del-T)                =  1.027
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 4.995E+03 | 1.364E+04 | 1.180E+05 | 8.65 | 48.71 |
| 2 | 3.18 | 4.834E+03 | 1.401E+04 | 1.122E+05 | 8.01 | 48.62 |
| 3 | 2.74 | 4.638E+03 | 1.449E+04 | 1.068E+05 | 7.37 | 48.68 |
| 4 | 2.30 | 4.365E+03 | 1.480E+04 | 9.953E+04 | 6.73 | 48.65 |
| 5 | 1.85 | 3.996E+03 | 1.484E+04 | 9.080E+04 | 6.12 | 48.72 |
| 6 | 1.41 | 3.561E+03 | 1.539E+04 | 7.982E+04 | 5.19 | 48.62 |
| 7 | 0.97 | 2.998E+03 | 1.665E+04 | 6.614E+04 | 3.97 | 48.63 |
| 8 | 1.41 | 3.545E+03 | 1.511E+04 | 7.963E+04 | 5.27 | 48.62 |
| 9 | 0.97 | 2.989E+03 | 1.670E+04 | 6.637E+04 | 3.98 | 48.67 |
| 10 | 1.85 | 4.001E+03 | 1.493E+04 | 9.108E+04 | 6.10 | 48.67 |
| 11 | 2.30 | 4.334E+03 | 1.446E+04 | 9.877E+04 | 6.83 | 48.63 |
| 12 | 2.74 | 4.628E+03 | 1.436E+04 | 1.059E+05 | 7.37 | 48.70 |
| 13 | 3.18 | 4.830E+03 | 1.392E+04 | 1.104E+05 | 7.93 | 48.65 |
| 14 | 3.62 | 5.056E+03 | 1.401E+04 | 1.156E+05 | 8.25 | 48.72 |
| 15 | 2.29 | 4.348E+03 | 1.455E+04 | 9.797E+04 | 6.73 | 48.65 |
| 16 | 0.97 | 3.024E+03 | 1.763E+04 | 6.515E+04 | 3.75 | 48.69 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.4722E-01
  Intercept   =  5.7933E+05

Least-squares line for q = a*delta-T^b
  a =  2.3546E+04
  b =  7.5000E-01


NOTE: 16 data points were stored in file FONMVNST1

NOTE: 16 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPOK
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMAHGT2
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.86 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.3893
Alpha (based on Nusselt (Tdel)) =  0.9933
Enhancement (q)                   =  1.402
Enhancement (Del-T)               =  1.289
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 1.85 | 5.666E+03 | 1.385E+04 | 4.083E+05 | 29.48 | 99.95 |
| 2 | 1.41 | 5.331E+03 | 1.432E+04 | 3.841E+05 | 26.83 | 99.98 |
| 3 | 0.97 | 4.821E+03 | 1.517E+04 | 3.453E+05 | 22.76 | 100.08 |
| 4 | 1.41 | 5.328E+03 | 1.432E+04 | 3.844E+05 | 26.84 | 99.89 |
| 5 | 0.97 | 4.842E+03 | 1.540E+04 | 3.475E+05 | 22.56 | 100.09 |
| 6 | 1.85 | 5.679E+03 | 1.397E+04 | 4.132E+05 | 29.58 | 100.05 |
| 7 | 2.29 | 5.932E+03 | 1.374E+04 | 4.326E+05 | 31.47 | 99.99 |
| 8 | 2.74 | 6.114E+03 | 1.354E+04 | 4.465E+05 | 32.98 | 99.97 |
| 9 | 3.18 | 6.271E+03 | 1.345E+04 | 4.584E+05 | 34.08 | 99.95 |
| 10 | 3.62 | 6.379E+03 | 1.330E+04 | 4.668E+05 | 35.10 | 100.01 |
| 11 | 3.18 | 6.278E+03 | 1.347E+04 | 4.585E+05 | 34.03 | 100.06 |
| 12 | 3.62 | 6.392E+03 | 1.335E+04 | 4.674E+05 | 35.01 | 100.04 |
| 13 | 2.74 | 6.130E+03 | 1.360E+04 | 4.460E+05 | 32.80 | 100.00 |
| 14 | 2.29 | 5.932E+03 | 1.372E+04 | 4.309E+05 | 31.40 | 100.02 |

```
Least-Squares Line for Ho vs q curve:
  Slope      = -2.1689E-01
  Intercept  =  7.6861E+05

Least-squares line for q = a*delta-T^b
  a =  3.2616E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMAHGT2

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAH6T3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3616
Alpha (based on Nusselt (Tdel)) = 1.0051
Ennancement (q) = 1.425
Enhancement (Del-T) = 1.304

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.62 | 6.405E+03 | 1.350E+04 | 4.721E+05 | 34.97 | 100.05 |
| 2 | 3.18 | 6.279E+03 | 1.358E+04 | 4.601E+05 | 33.89 | 99.89 |
| 3 | 2.74 | 6.154E+03 | 1.383E+04 | 4.500E+05 | 32.55 | 100.01 |
| 4 | 2.29 | 5.949E+03 | 1.394E+04 | 4.334E+05 | 31.09 | 99.93 |
| 5 | 1.85 | 5.704E+03 | 1.425E+04 | 4.142E+05 | 29.06 | 99.89 |
| 6 | 1.41 | 5.321E+03 | 1.446E+04 | 3.857E+05 | 26.68 | 100.01 |
| 7 | 0.97 | 4.825E+03 | 1.557E+04 | 3.481E+05 | 22.36 | 100.02 |
| 8 | 1.41 | 5.333E+03 | 1.455E+04 | 3.874E+05 | 26.61 | 100.05 |
| 9 | 2.30 | 5.951E+03 | 1.397E+04 | 4.349E+05 | 31.14 | 99.91 |
| 10 | 3.18 | 6.274E+03 | 1.355E+04 | 4.611E+05 | 34.02 | 100.01 |

Least-Squares Line for Ho vs q curve:
Slope = -2.1564E-01
Intercept = 7.6915E+05

Least-squares line for q = a*delta-T^b
a = 3.3011E+04
b = 7.5000E-01

NOTE: 10 data points were stored in file FONMAH6T3

NOTE: 10 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMAN6T1
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.86 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement     : WIRE-WRAPPED SMOOTH TUBE
      Tube material        : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  1.1204
Alpha (based on Nusselt (Tdel)) =  1.0190
Enhancement (q)                   =  1.465
Enhancement (Del-T)               =  1.331
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.62 | 5.436E+03 | 1.471E+04 | 3.946E+05 | 25.83 | 99.95 |
| 2 | 3.17 | 5.295E+03 | 1.527E+04 | 3.831E+05 | 25.10 | 99.96 |
| 3 | 2.73 | 5.044E+03 | 1.531E+04 | 3.643E+05 | 23.79 | 99.91 |
| 4 | 2.29 | 4.772E+03 | 1.571E+04 | 3.446E+05 | 21.93 | 99.93 |
| 5 | 1.85 | 4.410E+03 | 1.601E+04 | 3.186E+05 | 19.89 | 100.03 |
| 6 | 1.41 | 3.939E+03 | 1.638E+04 | 2.839E+05 | 17.33 | 99.93 |
| 7 | 0.97 | 3.365E+03 | 1.860E+04 | 2.419E+05 | 13.01 | 100.02 |
| 8 | 1.41 | 3.915E+03 | 1.605E+04 | 2.837E+05 | 17.58 | 100.07 |
| 9 | 0.97 | 3.370E+03 | 1.881E+04 | 2.421E+05 | 12.87 | 99.97 |
| 10 | 1.85 | 4.404E+03 | 1.605E+04 | 3.197E+05 | 19.92 | 99.93 |
| 11 | 2.29 | 4.762E+03 | 1.569E+04 | 3.458E+05 | 22.04 | 99.91 |
| 12 | 2.73 | 5.056E+03 | 1.548E+04 | 3.669E+05 | 23.71 | 99.97 |
| 13 | 3.17 | 5.290E+03 | 1.523E+04 | 3.926E+05 | 25.12 | 99.89 |
| 14 | 3.62 | 5.472E+03 | 1.495E+04 | 3.960E+05 | 25.50 | 99.98 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -1.7416E-01
  Intercept   =  7.5469E+05

Least-squares line for q = a*delta-T^b
  a =  3.4038E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMAN6T1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVH6T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.1602
Alpha (based on Nusselt (Tdel)) = 0.9498
Enhancement (q) = 1.330
Enhancement (Del-T) = 1.238

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 6.503E+03 | 1.468E+04 | 1.602E+05 | 10.92 | 48.76 |
| 2 | 3.19 | 6.324E+03 | 1.459E+04 | 1.530E+05 | 10.48 | 48.55 |
| 3 | 2.74 | 6.140E+03 | 1.468E+04 | 1.489E+05 | 10.14 | 48.73 |
| 4 | 2.30 | 5.961E+03 | 1.514E+04 | 1.430E+05 | 9.45 | 48.59 |
| 5 | 1.86 | 5.626E+03 | 1.512E+04 | 1.352E+05 | 8.94 | 48.75 |
| 6 | 0.97 | 4.703E+03 | 1.707E+04 | 1.099E+05 | 6.44 | 48.65 |
| 7 | 1.41 | 5.222E+03 | 1.549E+04 | 1.246E+05 | 8.04 | 48.67 |
| 8 | 2.30 | 5.930E+03 | 1.495E+04 | 1.430E+05 | 9.57 | 48.64 |
| 9 | 3.19 | 6.329E+03 | 1.462E+04 | 1.540E+05 | 10.53 | 48.67 |
| 10 | 1.41 | 5.229E+03 | 1.554E+04 | 1.241E+05 | 7.99 | 48.59 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4792E-01
Intercept = 5.3256E+05

Least-squares line for q = a*delta-T^b
a = 2.6385E+04
b = 7.5000E-01

NOTE: 10 data points were stored in file FONMVH6T1

NOTE: 10 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVH6T2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2144
Alpha (based on Nusselt (Tdel)) = 0.9460
Enhancement (q) = 1.323
Enhancement (Del-T) = 1.233

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 6.476E+03 | 1.438E+04 | 1.610E+05 | 11.20 | 48.70 |
| 2 | 3.19 | 6.318E+03 | 1.439E+04 | 1.570E+05 | 10.91 | 48.80 |
| 3 | 2.75 | 6.157E+03 | 1.459E+04 | 1.516E+05 | 10.39 | 48.64 |
| 4 | 2.30 | 5.945E+03 | 1.481E+04 | 1.454E+05 | 9.82 | 48.58 |
| 5 | 1.86 | 5.645E+03 | 1.498E+04 | 1.380E+05 | 9.21 | 48.55 |
| 6 | 1.42 | 5.228E+03 | 1.518E+04 | 1.278E+05 | 8.42 | 48.74 |
| 7 | 0.97 | 4.712E+03 | 1.663E+04 | 1.125E+05 | 6.77 | 48.55 |
| 8 | 1.42 | 5.250E+03 | 1.538E+04 | 1.287E+05 | 8.37 | 48.76 |
| 9 | 0.97 | 4.715E+03 | 1.667E+04 | 1.128E+05 | 6.77 | 48.56 |
| 10 | 1.86 | 5.635E+03 | 1.492E+04 | 1.382E+05 | 9.26 | 48.62 |
| 11 | 2.30 | 5.932E+03 | 1.474E+04 | 1.457E+05 | 9.88 | 48.56 |
| 12 | 2.75 | 6.159E+03 | 1.461E+04 | 1.523E+05 | 10.42 | 48.66 |
| 13 | 3.19 | 6.331E+03 | 1.447E+04 | 1.572E+05 | 10.86 | 48.71 |
| 14 | 3.63 | 6.490E+03 | 1.445E+04 | 1.610E+05 | 11.14 | 48.67 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4920E-01
Intercept = 5.8254E+05

Least-squares line for q = a*delta-T^b
a = 2.6267E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH6T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVN6T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0427
Alpha (based on Nusselt (Tdel)) = 1.0131
Enhancement (q) = 1.325
Enhancement (Del-T) = 1.235

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.471E+03 | 1.674E+04 | 1.360E+05 | 8.12 | 48.58 |
| 2 | 3.19 | 5.271E+03 | 1.713E+04 | 1.308E+05 | 7.64 | 48.63 |
| 3 | 2.75 | 5.035E+03 | 1.768E+04 | 1.244E+05 | 7.04 | 48.60 |
| 4 | 2.30 | 4.697E+03 | 1.769E+04 | 1.156E+05 | 6.53 | 48.58 |
| 5 | 1.86 | 4.296E+03 | 1.786E+04 | 1.059E+05 | 5.93 | 48.72 |
| 6 | 1.42 | 3.804E+03 | 1.838E+04 | 9.338E+04 | 5.08 | 48.70 |
| 7 | 0.97 | 3.210E+03 | 2.134E+04 | 7.770E+04 | 3.64 | 48.60 |
| 8 | 1.42 | 3.800E+03 | 1.834E+04 | 9.400E+04 | 5.13 | 48.75 |
| 9 | 0.97 | 3.201E+03 | 2.101E+04 | 7.757E+04 | 3.69 | 48.56 |
| 10 | 1.86 | 4.293E+03 | 1.790E+04 | 1.070E+05 | 5.98 | 48.77 |
| 11 | 2.30 | 4.693E+03 | 1.771E+04 | 1.169E+05 | 6.60 | 48.64 |
| 12 | 2.75 | 5.044E+03 | 1.784E+04 | 1.255E+05 | 7.04 | 48.57 |
| 13 | 3.19 | 5.276E+03 | 1.721E+04 | 1.313E+05 | 7.63 | 48.53 |
| 14 | 3.63 | 5.473E+03 | 1.677E+04 | 1.370E+05 | 8.17 | 48.69 |

Least-Squares Line for Ho vs q curve:
Slope = -2.0780E-01
Intercept = 5.7958E+05

Least-squares line for q = a*delta-T^b
a = 2.8413E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN6T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAH7T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2365
Alpha (based on Nusselt (Tdel)) = 0.9248
Enhancement (q) = 1.275
Enhancement (Del-T) = 1.200

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.61 | 6.067E+03 | 1.228E+04 | 4.375E+05 | 35.62 | 99.94 |
| 2 | 3.17 | 5.979E+03 | 1.243E+04 | 4.232E+05 | 34.06 | 99.94 |
| 3 | 2.73 | 5.823E+03 | 1.245E+04 | 4.095E+05 | 32.90 | 100.11 |
| 4 | 2.28 | 5.662E+03 | 1.267E+04 | 3.948E+05 | 31.17 | 99.96 |
| 5 | 1.84 | 5.397E+03 | 1.271E+04 | 3.745E+05 | 29.47 | 100.06 |
| 6 | 1.40 | 5.073E+03 | 1.306E+04 | 3.503E+05 | 26.82 | 99.95 |
| 7 | 0.97 | 4.609E+03 | 1.428E+04 | 3.254E+05 | 22.79 | 99.97 |
| 8 | 1.41 | 5.051E+03 | 1.321E+04 | 3.635E+05 | 27.52 | 99.93 |
| 9 | 0.97 | 4.604E+03 | 1.446E+04 | 3.310E+05 | 22.90 | 99.95 |
| 10 | 1.41 | 5.045E+03 | 1.323E+04 | 3.666E+05 | 27.70 | 100.00 |
| 11 | 1.85 | 5.360E+03 | 1.290E+04 | 3.936E+05 | 30.52 | 100.09 |
| 12 | 2.30 | 5.518E+03 | 1.267E+04 | 4.123E+05 | 32.55 | 100.06 |
| 13 | 2.74 | 5.829E+03 | 1.265E+04 | 4.282E+05 | 33.85 | 100.00 |
| 14 | 3.18 | 5.974E+03 | 1.253E+04 | 4.393E+05 | 35.06 | 99.97 |
| 15 | 3.62 | 6.062E+03 | 1.232E+04 | 4.465E+05 | 36.24 | 100.05 |
| 16 | 3.18 | 5.973E+03 | 1.252E+04 | 4.383E+05 | 35.01 | 99.95 |
| 17 | 3.62 | 6.070E+03 | 1.235E+04 | 4.457E+05 | 36.13 | 100.09 |
| 18 | 2.74 | 5.845E+03 | 1.271E+04 | 4.292E+05 | 33.63 | 99.97 |
| 19 | 2.30 | 5.630E+03 | 1.272E+04 | 4.117E+05 | 32.37 | 99.99 |
| 20 | 1.85 | 5.380E+03 | 1.288E+04 | 3.922E+05 | 30.44 | 100.02 |

Least-Squares Line for Ho vs q curve:
Slope = -2.2891E-01
Intercept = 7.6695E+05

Least-squares line for q = a*delta-T^b
a = 3.0311E+04
b = 7.5000E-01

NOTE: 20 data points were stored in file FONMAH7T1

NOTE: 20 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN7T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.36 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.1913
Alpha (based on Nusselt (Tdel)) = 0.3660
Enhancement (q) = 1.179
Enhancement (Del-T) = 1.131

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.149E+03 | 1.232E+04 | 3.830E+05 | 31.09 | 99.96 |
| 2 | 3.18 | 4.963E+03 | 1.228E+04 | 3.679E+05 | 29.95 | 99.99 |
| 3 | 2.74 | 4.764E+03 | 1.240E+04 | 3.532E+05 | 28.48 | 100.06 |
| 4 | 2.30 | 4.500E+03 | 1.242E+04 | 3.338E+05 | 26.88 | 100.08 |
| 5 | 1.86 | 4.189E+03 | 1.259E+04 | 3.100E+05 | 24.63 | 99.98 |
| 6 | 1.41 | 3.795E+03 | 1.299E+04 | 2.809E+05 | 21.61 | 100.08 |
| 7 | 0.97 | 3.319E+03 | 1.507E+04 | 2.442E+05 | 16.21 | 99.91 |
| 8 | 1.41 | 3.786E+03 | 1.292E+04 | 2.808E+05 | 21.73 | 100.06 |
| 9 | 0.97 | 3.308E+03 | 1.488E+04 | 2.439E+05 | 16.39 | 99.97 |
| 10 | 1.86 | 4.185E+03 | 1.261E+04 | 3.113E+05 | 24.69 | 99.97 |
| 11 | 2.30 | 4.491E+03 | 1.240E+04 | 3.345E+05 | 26.98 | 100.01 |
| 12 | 2.74 | 4.764E+03 | 1.243E+04 | 3.540E+05 | 29.47 | 99.90 |
| 13 | 3.18 | 4.968E+03 | 1.234E+04 | 3.698E+05 | 29.97 | 100.03 |
| 14 | 3.63 | 5.151E+03 | 1.232E+04 | 3.931E+05 | 31.09 | 100.04 |

Least-Squares Line for Ho vs q curve:
Slope = -2.1515E-01
Intercept = 7.5742E-05

Least-squares line for q = a*delta-T^b
a = 2.8701E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN7T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPGT
Data taken by : O'KEEFE
This analysis done on file : FONMVH7T2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.9559
Alpha (based on Nusselt (Tdel)) = 0.8552
Enhancement (q) = 1.156
Enhancement (Del-T) = 1.115

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 2.30 | 5.539E+03 | 1.355E+04 | 1.303E+05 | 9.61 | 48.63 |
| 2 | 1.86 | 5.230E+03 | 1.359E+04 | 1.219E+05 | 8.97 | 48.53 |
| 3 | 1.41 | 4.865E+03 | 1.405E+04 | 1.131E+05 | 8.05 | 48.65 |
| 4 | 0.97 | 4.349E+03 | 1.526E+04 | 1.006E+05 | 6.59 | 48.72 |
| 5 | 1.41 | 4.842E+03 | 1.387E+04 | 1.135E+05 | 8.18 | 48.72 |
| 6 | 1.41 | 4.871E+03 | 1.412E+04 | 1.136E+05 | 8.05 | 48.63 |
| 7 | 1.86 | 5.237E+03 | 1.365E+04 | 1.239E+05 | 9.07 | 48.70 |
| 8 | 2.30 | 5.516E+03 | 1.343E+04 | 1.305E+05 | 9.71 | 48.56 |
| 9 | 2.74 | 5.738E+03 | 1.332E+04 | 1.364E+05 | 10.25 | 48.64 |
| 10 | 3.18 | 5.886E+03 | 1.309E+04 | 1.408E+05 | 10.76 | 48.75 |
| 11 | 3.63 | 6.067E+03 | 1.320E+04 | 1.441E+05 | 10.92 | 48.53 |
| 12 | 3.18 | 5.872E+03 | 1.301E+04 | 1.405E+05 | 10.79 | 48.80 |
| 13 | 2.74 | 5.721E+03 | 1.322E+04 | 1.355E+05 | 10.25 | 48.65 |
| 14 | 2.30 | 5.544E+03 | 1.359E+04 | 1.307E+05 | 9.62 | 48.62 |

Least-Squares Line for Ho vs q curve:
Slope = -2.8347E-01
Intercept = 5.8361E+05

Least-squares line for q = a*delta-T^b
a = 2.3773E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH7T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPCV
Data taken by : O'KEEFE
This analysis done on file : FONMVN7T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 0.9775
Alpha (based on Nusselt (Tdel)) = 0.8700
Enhancement (q) = 1.081
Enhancement (Del-T) = 1.060

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 5.069E+03 | 1.436E+04 | 1.240E+05 | 8.64 | 48.53 |
| 2 | 3.19 | 4.829E+03 | 1.413E+04 | 1.180E+05 | 8.35 | 48.74 |
| 3 | 2.74 | 4.658E+03 | 1.490E+04 | 1.125E+05 | 7.55 | 48.61 |
| 4 | 2.30 | 4.341E+03 | 1.480E+04 | 1.052E+05 | 7.11 | 48.78 |
| 5 | 1.86 | 3.967E+03 | 1.477E+04 | 9.574E+04 | 6.48 | 48.81 |
| 6 | 1.41 | 3.557E+03 | 1.583E+04 | 8.537E+04 | 5.39 | 48.75 |
| 7 | 0.97 | 2.997E+03 | 1.783E+04 | 7.072E+04 | 3.97 | 48.56 |
| 8 | 1.41 | 3.562E+03 | 1.596E+04 | 8.559E+04 | 5.36 | 48.68 |
| 9 | 0.97 | 2.977E+03 | 1.719E+04 | 7.082E+04 | 4.12 | 48.67 |
| 10 | 1.86 | 3.983E+03 | 1.505E+04 | 9.639E+04 | 6.41 | 48.68 |
| 11 | 2.30 | 4.339E+03 | 1.480E+04 | 1.051E+05 | 7.10 | 48.67 |
| 12 | 2.74 | 4.633E+03 | 1.465E+04 | 1.127E+05 | 7.70 | 48.76 |
| 13 | 3.19 | 4.828E+03 | 1.410E+04 | 1.180E+05 | 8.37 | 48.85 |
| 14 | 3.63 | 5.090E+03 | 1.447E+04 | 1.236E+05 | 8.54 | 48.72 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4125E-01
Intercept = 5.7963E+05

Least-squares line for q = a*delta-T^b
a = 2.4307E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN7T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHLT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.9032
Alpha (based on Nusselt (Tdel)) = 0.9029
Enhancement (q) = 1.235
Enhancement (Del-T) = 1.171

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 1.03 | 4.746E+03 | 1.321E+04 | 3.432E+05 | 25.98 | 100.00 |
| 2 | 1.49 | 5.182E+03 | 1.291E+04 | 3.747E+05 | 29.04 | 100.01 |
| 3 | 1.96 | 5.431E+03 | 1.255E+04 | 3.909E+05 | 31.14 | 100.05 |
| 4 | 2.43 | 5.611E+03 | 1.238E+04 | 4.029E+05 | 32.56 | 99.95 |
| 5 | 2.89 | 5.757E+03 | 1.231E+04 | 4.129E+05 | 33.54 | 99.99 |
| 6 | 3.36 | 5.842E+03 | 1.213E+04 | 4.175E+05 | 34.41 | 99.95 |
| 7 | 3.82 | 5.913E+03 | 1.204E+04 | 4.222E+05 | 35.07 | 99.99 |
| 8 | 3.35 | 5.833E+03 | 1.208E+04 | 4.143E+05 | 34.30 | 99.99 |
| 9 | 3.82 | 5.926E+03 | 1.206E+04 | 4.208E+05 | 34.89 | 100.02 |
| 10 | 2.89 | 5.755E+03 | 1.226E+04 | 4.069E+05 | 33.18 | 99.97 |
| 11 | 2.42 | 5.629E+03 | 1.242E+04 | 3.985E+05 | 32.09 | 99.95 |
| 12 | 1.96 | 5.433E+03 | 1.254E+04 | 3.881E+05 | 30.96 | 99.93 |
| 13 | 1.49 | 5.176E+03 | 1.282E+04 | 3.708E+05 | 29.93 | 100.02 |
| 14 | 1.03 | 4.765E+03 | 1.326E+04 | 3.401E+05 | 25.64 | 99.91 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4802E-01
Intercept = 7.7226E+05

Least-squares line for q = a*delta-T^b
a = 2.9569E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHLT2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHLT3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8921
Alpha (based on Nusselt (Tdel)) = 0.9159
Enhancement (q) = 1.259
Enhancement (Del-T) = 1.188

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.83 | 5.902E+03 | 1.203E+04 | 4.313E+05 | 35.84 | 100.05 |
| 2 | 3.36 | 5.842E+03 | 1.219E+04 | 4.256E+05 | 34.90 | 99.93 |
| 3 | 2.90 | 5.778E+03 | 1.247E+04 | 4.206E+05 | 33.74 | 100.04 |
| 4 | 2.43 | 5.625E+03 | 1.250E+04 | 4.085E+05 | 32.67 | 100.01 |
| 5 | 1.96 | 5.466E+03 | 1.280E+04 | 3.958E+05 | 30.93 | 99.97 |
| 6 | 1.49 | 5.195E+03 | 1.302E+04 | 3.754E+05 | 28.83 | 99.94 |
| 7 | 1.03 | 4.782E+03 | 1.348E+04 | 3.429E+05 | 25.44 | 99.94 |
| 8 | 1.96 | 5.431E+03 | 1.262E+04 | 3.949E+05 | 31.29 | 100.03 |
| 9 | 2.43 | 5.647E+03 | 1.262E+04 | 4.114E+05 | 32.59 | 99.97 |
| 10 | 2.90 | 5.783E+03 | 1.250E+04 | 4.219E+05 | 33.76 | 99.99 |
| 11 | 3.83 | 5.929E+03 | 1.215E+04 | 4.335E+05 | 35.67 | 99.95 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4475E-01
Intercept = 7.7234E+05

Least-squares line for q = a*delta-T^b
a = 2.9951E+04
b = 7.5000E-01

NOTE: 11 data points were stored in file FONMAHLT3

NOTE: 11 X-Y pairs were stored in data file

NOTE: Program name : DRP[illegible]
Data taken by : O'KEEFE
This analysis done on file : FONMANLT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0556
Alpha (based on Nusselt (Tdel)) = 0.9191
Enhancement (q) = 1.275
Enhancement (Del-T) = 1.201

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 2.43 | 5.306E+03 | 1.317E+04 | 3.858E+05 | 29.30 | 99.96 |
| 2 | 1.96 | 5.055E+03 | 1.324E+04 | 3.664E+05 | 27.68 | 100.07 |
| 3 | 1.49 | 4.759E+03 | 1.376E+04 | 3.428E+05 | 24.91 | 99.88 |
| 4 | 1.03 | 4.246E+03 | 1.411E+04 | 3.054E+05 | 21.64 | 100.03 |
| 5 | 1.49 | 4.724E+03 | 1.350E+04 | 3.419E+05 | 25.32 | 99.98 |
| 6 | 1.03 | 4.253E+03 | 1.420E+04 | 3.057E+05 | 21.53 | 99.90 |
| 7 | 1.96 | 5.053E+03 | 1.325E+04 | 3.677E+05 | 27.74 | 100.05 |
| 8 | 2.43 | 5.297E+03 | 1.310E+04 | 3.847E+05 | 29.35 | 99.95 |
| 9 | 2.90 | 5.451E+03 | 1.293E+04 | 3.960E+05 | 30.85 | 99.94 |
| 10 | 3.36 | 5.578E+03 | 1.266E+04 | 4.051E+05 | 31.99 | 99.98 |
| 11 | 3.83 | 5.632E+03 | 1.231E+04 | 4.086E+05 | 33.20 | 99.37 |
| 12 | 3.36 | 5.569E+03 | 1.261E+04 | 4.042E+05 | 32.05 | 100.07 |
| 13 | 3.83 | 5.636E+03 | 1.232E+04 | 4.088E+05 | 33.19 | 100.02 |
| 14 | 2.89 | 5.460E+03 | 1.286E+04 | 3.951E+05 | 30.73 | 100.11 |

Least-Squares Line for Ho vs q curve:
Slope = -2.2369E-01
Intercept = 7.6648E+05

Least-squares line for q = a*delta-T^b
a = 3.0263E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANLT2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DR[illegible]
Data taken by : O'KEEFE
This analysis done on file : FONMANLT3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.9930
Alpha (based on Nusselt (Tdel)) = 0.9411
Enhancement (q) = 1.317
Enhancement (Del-T) = 1.230

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 2.43 | 5.283E+03 | 1.333E+04 | 3.852E+05 | 28.91 | 99.85 |
| 2 | 1.96 | 5.049E+03 | 1.355E+04 | 3.662E+05 | 27.02 | 99.94 |
| 3 | 1.49 | 4.761E+03 | 1.425E+04 | 3.439E+05 | 24.13 | 100.03 |
| 4 | 1.03 | 4.246E+03 | 1.475E+04 | 3.046E+05 | 20.64 | 99.96 |
| 5 | 1.49 | 4.751E+03 | 1.417E+04 | 3.432E+05 | 24.22 | 100.00 |
| 6 | 1.03 | 4.253E+03 | 1.482E+04 | 3.048E+05 | 20.56 | 99.97 |
| 7 | 1.96 | 5.078E+03 | 1.375E+04 | 3.674E+05 | 26.72 | 99.93 |
| 8 | 2.43 | 5.316E+03 | 1.349E+04 | 3.855E+05 | 28.57 | 100.03 |
| 9 | 2.89 | 5.464E+03 | 1.313E+04 | 3.963E+05 | 30.18 | 99.94 |
| 10 | 3.36 | 5.593E+03 | 1.294E+04 | 4.063E+05 | 31.40 | 100.09 |
| 11 | 3.83 | 5.664E+03 | 1.263E+04 | 4.113E+05 | 32.57 | 100.04 |

Least-Squares Line for Ho vs q curve:
Slope = -2.2725E-01
Intercept = 7.6783E+05

Least-squares line for q = a*delta-T^b
a = 3.1076E+04
b = 7.5000E-01

NOTE: 11 data points were stored in file FONMANLT3

NOTE: 11 X-Y pairs were stored in data file

NOTE: Program name : DRP3K
Data taken by : O'KEEFE
This analysis done on file : FONMVHLT1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.7173
Alpha (based on Nusselt (Tdel)) = 0.9449
Enhancement (q) = 1.321
Enhancement (Del-T) = 1.232

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 1.03 | 4.900E+03 | 1.624E+04 | 1.195E+05 | 7.36 | 48.68 |
| 2 | 1.50 | 5.386E+03 | 1.546E+04 | 1.316E+05 | 8.51 | 48.69 |
| 3 | 1.97 | 5.700E+03 | 1.506E+04 | 1.397E+05 | 9.28 | 48.64 |
| 4 | 2.44 | 5.912E+03 | 1.473E+04 | 1.456E+05 | 9.89 | 48.73 |
| 5 | 2.91 | 6.143E+03 | 1.492E+04 | 1.503E+05 | 10.07 | 48.61 |
| 6 | 3.38 | 6.209E+03 | 1.442E+04 | 1.526E+05 | 10.58 | 48.72 |
| 7 | 3.84 | 6.311E+03 | 1.431E+04 | 1.550E+05 | 10.83 | 48.72 |
| 8 | 3.37 | 6.240E+03 | 1.459E+04 | 1.519E+05 | 10.41 | 48.63 |
| 9 | 3.84 | 6.326E+03 | 1.438E+04 | 1.543E+05 | 10.73 | 48.65 |
| 10 | 2.91 | 6.112E+03 | 1.472E+04 | 1.485E+05 | 10.09 | 48.74 |
| 11 | 2.44 | 5.937E+03 | 1.485E+04 | 1.430E+05 | 9.63 | 48.54 |
| 12 | 1.97 | 5.729E+03 | 1.520E+04 | 1.375E+05 | 9.05 | 48.70 |
| 13 | 1.50 | 5.370E+03 | 1.525E+04 | 1.277E+05 | 8.38 | 48.69 |
| 14 | 1.03 | 4.890E+03 | 1.597E+04 | 1.152E+05 | 7.21 | 48.70 |

Least-Squares Line for Ho vs q curve:
Slope = -2.6049E-01
Intercept = 5.8423E+05

Least-squares line for q = a*delta-T^b
a = 2.6230E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHLT1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVHLT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.6688
Alpha (based on Nusselt (Tdel)) = 0.9496
Enhancement (q) = 1.329
Enhancement (Del-T) = 1.238

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.84 | 6.322E+03 | 1.446E+04 | 1.542E+05 | 10.66 | 48.63 |
| 2 | 3.37 | 6.238E+03 | 1.469E+04 | 1.519E+05 | 10.34 | 48.70 |
| 3 | 2.91 | 6.078E+03 | 1.466E+04 | 1.473E+05 | 10.05 | 48.68 |
| 4 | 2.44 | 5.927E+03 | 1.495E+04 | 1.429E+05 | 9.56 | 48.68 |
| 5 | 1.97 | 5.730E+03 | 1.541E+04 | 1.371E+05 | 8.90 | 48.66 |
| 6 | 1.50 | 5.388E+03 | 1.565E+04 | 1.281E+05 | 8.18 | 48.69 |
| 7 | 1.03 | 4.878E+03 | 1.622E+04 | 1.149E+05 | 7.08 | 48.65 |
| 8 | 1.97 | 5.706E+03 | 1.525E+04 | 1.377E+05 | 9.03 | 48.68 |
| 9 | 2.44 | 5.941E+03 | 1.505E+04 | 1.442E+05 | 9.58 | 48.64 |
| 10 | 2.91 | 6.095E+03 | 1.477E+04 | 1.489E+05 | 10.08 | 48.69 |
| 11 | 3.94 | 6.329E+03 | 1.451E+04 | 1.554E+05 | 10.71 | 48.68 |
| 12 | 1.03 | 4.891E+03 | 1.636E+04 | 1.149E+05 | 7.02 | 48.63 |

Least-Squares Line for Ho vs q curve:
Slope = -2.5633E-01
Intercept = 5.8376E+05

Least-squares line for q = a*delta-T^b
a = 2.6375E+04
b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVHLT2

NOTE: 12 X-Y pairs were stored in data file

```
NOTE: Program name : DRP9KT
      Data taken by              : O'KEEFE
      This analysis done on file : FONMVNLT2
      This analysis includes end-fin effect
      Thermal conductivity       =  21.0 (W/m.K)
      Inside diameter, Di        = 13.47 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement    : LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  1.8686
Alpha (based on Nusselt (Tdel)) =  0.9526
Enhancement (q)                  =  1.220
Enhancement (Del-T)              =  1.161
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 1.03 | 4.188E+03 | 1.659E+04 | 1.007E+05 | 6.07 | 48.69 |
| 2 | 1.50 | 4.779E+03 | 1.625E+04 | 1.164E+05 | 7.16 | 48.67 |
| 3 | 1.97 | 5.207E+03 | 1.624E+04 | 1.286E+05 | 7.92 | 48.72 |
| 4 | 2.44 | 5.441E+03 | 1.550E+04 | 1.349E+05 | 8.70 | 48.74 |
| 5 | 2.91 | 5.660E+03 | 1.532E+04 | 1.403E+05 | 9.16 | 48.68 |
| 6 | 3.38 | 5.782E+03 | 1.483E+04 | 1.432E+05 | 9.66 | 48.64 |
| 7 | 3.85 | 5.873E+03 | 1.442E+04 | 1.455E+05 | 10.08 | 48.65 |
| 8 | 2.91 | 5.689E+03 | 1.552E+04 | 1.405E+05 | 9.05 | 48.72 |
| 9 | 3.85 | 5.894E+03 | 1.455E+04 | 1.462E+05 | 10.05 | 48.72 |
| 10 | 2.44 | 5.475E+03 | 1.576E+04 | 1.340E+05 | 8.51 | 48.60 |
| 11 | 1.97 | 5.189E+03 | 1.604E+04 | 1.270E+05 | 7.91 | 48.70 |
| 12 | 1.03 | 4.239E+03 | 1.736E+04 | 1.013E+05 | 5.83 | 48.70 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.5018E-01
  Intercept   =  5.8313E+05

Least-squares line for q = a*delta-T^b
  a =  2.6547E+04
  b =  7.5000E-01


NOTE: 12 data points were stored in file FONMVNLT2

NOTE: 12 X-Y pairs were stored in data file
```

NOTE: Program name : DRPGM
Data taken by : O'KEEFE
This analysis done on file : FONMVNLT3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.8615
Alpha (based on Nusselt (Tdel)) = 0.9563
Enhancement (q) = 1.226
Enhancement (Del-T) = 1.165

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 1.50 | 4.781E+03 | 1.636E+04 | 1.161E+05 | 7.10 | 48.61 |
| 2 | 1.03 | 4.190E+03 | 1.678E+04 | 1.009E+05 | 6.02 | 48.64 |
| 3 | 1.50 | 4.813E+03 | 1.675E+04 | 1.177E+05 | 7.03 | 48.74 |
| 4 | 1.97 | 5.180E+03 | 1.604E+04 | 1.273E+05 | 7.93 | 48.69 |
| 5 | 2.44 | 5.470E+03 | 1.578E+04 | 1.348E+05 | 8.54 | 48.63 |
| 6 | 2.91 | 5.675E+03 | 1.547E+04 | 1.408E+05 | 9.10 | 48.72 |
| 7 | 3.38 | 5.781E+03 | 1.486E+04 | 1.434E+05 | 9.65 | 48.67 |
| 8 | 3.85 | 5.924E+03 | 1.477E+04 | 1.470E+05 | 9.96 | 48.63 |
| 9 | 3.38 | 5.731E+03 | 1.485E+04 | 1.433E+05 | 9.65 | 48.74 |
| 10 | 3.85 | 5.881E+03 | 1.450E+04 | 1.456E+05 | 10.04 | 48.70 |
| 11 | 2.91 | 5.693E+03 | 1.558E+04 | 1.397E+05 | 8.97 | 48.65 |
| 12 | 2.44 | 5.473E+03 | 1.579E+04 | 1.340E+05 | 8.49 | 48.58 |
| 13 | 1.97 | 5.198E+03 | 1.618E+04 | 1.262E+05 | 7.80 | 48.53 |
| 14 | 1.03 | 4.217E+03 | 1.717E+04 | 1.011E+05 | 5.99 | 48.67 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4579E-01
Intercept = 5.8265E+05

Least-squares line for q = a*delta-T^b
a = 2.6648E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNLT3

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOV
Data taken by : O'KEEFE
This analysis done on file : FONMAHL1T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.6673
Alpha (based on Nusselt (Tdel)) = 0.8897
Enhancement (q) = 1.211
Enhancement (Del-T) = 1.154

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 2.43 | 5.447E+03 | 1.212E+04 | 3.997E+05 | 32.98 | 100.05 |
| 2 | 1.96 | 5.263E+03 | 1.230E+04 | 3.850E+05 | 31.29 | 99.98 |
| 3 | 1.50 | 5.002E+03 | 1.260E+04 | 3.649E+05 | 28.96 | 99.96 |
| 4 | 1.03 | 4.605E+03 | 1.323E+04 | 3.332E+05 | 25.19 | 99.87 |
| 5 | 1.50 | 4.996E+03 | 1.257E+04 | 3.648E+05 | 29.03 | 99.98 |
| 6 | 1.03 | 4.594E+03 | 1.315E+04 | 3.334E+05 | 25.35 | 99.99 |
| 7 | 1.96 | 5.251E+03 | 1.225E+04 | 3.848E+05 | 31.42 | 99.91 |
| 8 | 2.43 | 5.443E+03 | 1.211E+04 | 4.003E+05 | 33.05 | 99.98 |
| 9 | 2.90 | 5.607E+03 | 1.210E+04 | 4.124E+05 | 34.08 | 100.01 |
| 10 | 3.37 | 5.698E+03 | 1.193E+04 | 4.195E+05 | 35.16 | 100.04 |
| 11 | 3.83 | 5.767E+03 | 1.178E+04 | 4.241E+05 | 35.99 | 99.96 |
| 12 | 3.37 | 5.675E+03 | 1.182E+04 | 4.170E+05 | 35.27 | 100.02 |
| 13 | 3.83 | 5.767E+03 | 1.178E+04 | 4.243E+05 | 36.00 | 100.02 |
| 14 | 2.90 | 5.583E+03 | 1.198E+04 | 4.092E+05 | 34.16 | 100.01 |
| 15 | 2.43 | 5.445E+03 | 1.210E+04 | 3.983E+05 | 32.91 | 100.01 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4945E-01
Intercept = 7.7129E+05

Least-squares line for q = a*delta-T^b
a = 2.9099E+04
b = 7.5000E-01

NOTE: 15 data points were stored in file FONMAHL1T1

NOTE: 15 X-Y pairs were stored in data file

```
NOTE: Program name : DRP09T
      Data taken by               : O'KEEFE
      This analysis done on file : FONMANL1T1
      This analysis includes end-fin effect
      Thermal conductivity        =  21.0 (W/m.K)
      Inside diameter, Di         = 13.47 (mm)
      Outside diameter, Do        = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  2.0362
Alpha (based on Nusselt (Tdel)) =  0.8688
Enhancement (q)                   =  1.184
Enhancement (Del-T)               =  1.135
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.84 | 5.440E+03 | 1.152E+04 | 4.025E+05 | 34.93 | 99.97 |
| 2 | 3.37 | 5.362E+03 | 1.170E+04 | 3.954E+05 | 33.79 | 99.98 |
| 3 | 2.90 | 5.285E+03 | 1.206E+04 | 3.893E+05 | 32.28 | 100.07 |
| 4 | 2.43 | 5.121E+03 | 1.220E+04 | 3.752E+05 | 30.76 | 99.85 |
| 5 | 1.96 | 4.889E+03 | 1.230E+04 | 3.571E+05 | 29.03 | 99.89 |
| 6 | 1.49 | 4.591E+03 | 1.265E+04 | 3.355E+05 | 26.52 | 100.04 |
| 7 | 1.03 | 4.135E+03 | 1.324E+04 | 3.003E+05 | 22.69 | 99.96 |
| 8 | 1.50 | 4.586E+03 | 1.263E+04 | 3.359E+05 | 26.60 | 100.08 |
| 9 | 1.03 | 4.132E+03 | 1.322E+04 | 3.003E+05 | 22.71 | 99.94 |
| 10 | 1.96 | 4.891E+03 | 1.234E+04 | 3.589E+05 | 29.09 | 99.90 |
| 11 | 2.43 | 5.125E+03 | 1.224E+04 | 3.774E+05 | 30.83 | 99.95 |
| 12 | 2.90 | 5.247E+03 | 1.187E+04 | 3.866E+05 | 32.58 | 99.97 |
| 13 | 3.37 | 5.363E+03 | 1.171E+04 | 3.956E+05 | 33.79 | 99.94 |
| 14 | 3.84 | 5.447E+03 | 1.155E+04 | 4.017E+05 | 34.79 | 99.91 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.5035E-01
  Intercept  =  7.6937E+05

Least-squares line for q = a*delta-T^b
  a =  2.8535E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMANL1T1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DR89T
Data taken by : O'KEEFE
This analysis done on file : FONMVHL1T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3166
Alpha (based on Nusselt (Tdel)) = 0.8799
Enhancement (q) = 1.201
Enhancement (Del-T) = 1.147

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.84 | 6.001E+03 | 1.363E+04 | 1.471E+05 | 10.80 | 48.64 |
| 2 | 3.37 | 5.859E+03 | 1.355E+04 | 1.427E+05 | 10.53 | 48.66 |
| 3 | 2.91 | 5.700E+03 | 1.355E+04 | 1.390E+05 | 10.26 | 48.78 |
| 4 | 2.44 | 5.510E+03 | 1.360E+04 | 1.340E+05 | 9.85 | 48.74 |
| 5 | 1.97 | 5.275E+03 | 1.378E+04 | 1.281E+05 | 9.30 | 48.81 |
| 6 | 1.50 | 5.002E+03 | 1.450E+04 | 1.195E+05 | 8.24 | 48.54 |
| 7 | 1.03 | 4.510E+03 | 1.520E+04 | 1.074E+05 | 7.07 | 48.65 |
| 8 | 1.50 | 4.998E+03 | 1.448E+04 | 1.202E+05 | 8.30 | 48.59 |
| 9 | 1.03 | 4.507E+03 | 1.516E+04 | 1.079E+05 | 7.11 | 48.74 |
| 10 | 1.97 | 5.292E+03 | 1.391E+04 | 1.286E+05 | 9.24 | 48.60 |
| 11 | 2.44 | 5.516E+03 | 1.366E+04 | 1.347E+05 | 9.86 | 48.57 |
| 12 | 2.91 | 5.698E+03 | 1.355E+04 | 1.400E+05 | 10.33 | 48.67 |
| 13 | 3.38 | 5.863E+03 | 1.359E+04 | 1.436E+05 | 10.57 | 48.61 |
| 14 | 3.84 | 5.998E+03 | 1.361E+04 | 1.470E+05 | 10.79 | 48.59 |

Least-Squares Line for Ho vs q curve:
Slope = -2.7629E-01
Intercept = 5.8368E+05

Least-squares line for q = a*delta-T^b
a = 2.4437E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL1T1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DR[illegible] 691
      Data taken by               : O'KEEFE
      This analysis done on file : FONMVNL1T1
      This analysis includes end-fin effect
      Thermal conductivity       =  21.0 (W/m.K)
      Inside diameter, Di        = 13.47 (mm)
      Outside diameter, Do       = 15.85 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED LPD KORODENSE TUBE
      Tube material       : TITANIUM
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)     =  1.7837
Alpha (based on Nusselt (Tdel)) =  0.8545
Enhancement (q)                  =  1.056
Enhancement (Del-T)              =  1.041
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.38 | 5.480E+03 | 1.334E+04 | 1.347E+05 | 10.10 | 48.60 |
| 2 | 2.91 | 5.342E+03 | 1.359E+04 | 1.305E+05 | 9.60 | 48.56 |
| 3 | 2.44 | 5.123E+03 | 1.363E+04 | 1.255E+05 | 9.21 | 48.79 |
| 4 | 1.97 | 4.852E+03 | 1.377E+04 | 1.180E+05 | 8.57 | 48.73 |
| 5 | 1.50 | 4.519E+03 | 1.434E+04 | 1.093E+05 | 7.62 | 48.74 |
| 6 | 1.03 | 3.996E+03 | 1.508E+04 | 9.583E+04 | 6.35 | 48.67 |
| 7 | 1.50 | 4.528E+03 | 1.447E+04 | 1.096E+05 | 7.58 | 48.50 |
| 8 | 1.03 | 3.992E+03 | 1.504E+04 | 9.598E+04 | 6.38 | 48.69 |
| 9 | 1.97 | 4.854E+03 | 1.381E+04 | 1.188E+05 | 8.60 | 48.67 |
| 10 | 2.44 | 5.132E+03 | 1.371E+04 | 1.264E+05 | 9.22 | 48.74 |
| 11 | 2.91 | 5.309E+03 | 1.338E+04 | 1.307E+05 | 9.77 | 48.74 |
| 12 | 3.38 | 5.470E+03 | 1.327E+04 | 1.336E+05 | 10.07 | 48.59 |
| 13 | 3.84 | 5.597E+03 | 1.317E+04 | 1.375E+05 | 10.44 | 48.70 |
| 14 | 3.37 | 5.464E+03 | 1.323E+04 | 1.338E+05 | 10.11 | 48.70 |
| 15 | 3.84 | 5.589E+03 | 1.312E+04 | 1.371E+05 | 10.46 | 48.73 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.8007E-01
  Intercept   =  5.8324E+05

Least-squares line for q = a*delta-T^b
  a =  2.3759E+04
  b =  7.5000E-01


NOTE: 15 data points were stored in file FONMVNL1T1

NOTE: 15 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHL2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.6388
Alpha (based on Nusselt (Tdel)) = 0.9089
Enhancement (q) = 1.246
Enhancement (Del-T) = 1.179

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.84 | 5.829E+03 | 1.210E+04 | 4.313E+05 | 35.63 | 99.96 |
| 2 | 3.37 | 5.755E+03 | 1.223E+04 | 4.238E+05 | 34.64 | 99.99 |
| 3 | 2.90 | 5.641E+03 | 1.231E+04 | 4.143E+05 | 33.64 | 99.96 |
| 4 | 2.43 | 5.520E+03 | 1.255E+04 | 4.043E+05 | 32.23 | 99.99 |
| 5 | 1.96 | 5.331E+03 | 1.276E+04 | 3.892E+05 | 30.51 | 99.93 |
| 6 | 1.49 | 5.020E+03 | 1.281E+04 | 3.661E+05 | 28.58 | 100.08 |
| 7 | 1.03 | 4.643E+03 | 1.369E+04 | 3.362E+05 | 24.55 | 100.01 |
| 8 | 1.50 | 5.026E+03 | 1.286E+04 | 3.667E+05 | 29.51 | 99.56 |
| 9 | 1.03 | 4.622E+03 | 1.353E+04 | 3.356E+05 | 24.81 | 100.12 |
| 10 | 1.96 | 5.304E+03 | 1.261E+04 | 3.883E+05 | 30.79 | 99.96 |
| 11 | 2.43 | 5.494E+03 | 1.243E+04 | 4.030E+05 | 32.43 | 99.92 |
| 12 | 2.90 | 5.640E-03 | 1.231E+04 | 4.143E+05 | 33.56 | 99.37 |
| 13 | 3.37 | 5.747E+03 | 1.219E+04 | 4.228E+05 | 34.63 | 99.99 |
| 14 | 3.83 | 5.824E+03 | 1.207E-04 | 4.290E+05 | 35.55 | 100.02 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4705E-01
Intercept = 7.7249E+05

Least-squares line for q = a*delta-T^b
a = 2.9774E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK1
Data taken by : O'KEEFE
This analysis done on file : FONMANL2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0573
Alpha (based on Nusselt (Tdel)) = 0.8901
Enhancement (q) = 1.223
Enhancement (Del-T) = 1.163

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.84 | 5.574E+03 | 1.207E+04 | 4.108E+05 | 34.03 | 99.92 |
| 2 | 3.37 | 5.450E+03 | 1.207E+04 | 4.012E+05 | 33.25 | 99.99 |
| 3 | 2.90 | 5.330E+03 | 1.222E+04 | 3.918E+05 | 32.06 | 100.00 |
| 4 | 2.43 | 5.189E+03 | 1.251E+04 | 3.811E+05 | 30.46 | 100.04 |
| 5 | 1.96 | 4.967E+03 | 1.272E+04 | 3.639E+05 | 28.61 | 99.95 |
| 6 | 1.49 | 4.670E+03 | 1.313E+04 | 3.407E+05 | 25.95 | 99.94 |
| 7 | 1.03 | 4.182E+03 | 1.353E+04 | 3.038E+05 | 22.46 | 100.02 |
| 8 | 1.50 | 4.663E+03 | 1.309E+04 | 3.410E+05 | 25.04 | 99.95 |
| 9 | 1.03 | 4.195E+03 | 1.369E+04 | 3.052E+05 | 22.29 | 100.00 |
| 10 | 1.96 | 4.957E+03 | 1.267E+04 | 3.650E+05 | 28.80 | 100.06 |
| 11 | 2.43 | 5.165E+03 | 1.238E+04 | 3.805E+05 | 30.73 | 100.08 |
| 12 | 2.90 | 5.315E+03 | 1.215E+04 | 3.911E+05 | 32.19 | 99.93 |
| 13 | 3.37 | 5.444E+03 | 1.204E+04 | 4.019E+05 | 33.37 | 100.05 |
| 14 | 3.84 | 5.552E+03 | 1.197E+04 | 4.094E+05 | 34.20 | 99.98 |

Least-Squares Line for Ho vs q curve:
Slope = -2.4184E-01
Intercept = 7.6857E+05

Least-squares line for q = a*delta-T^b
a = 2.9268E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPLT
Data taken by : O'KEEFE
This analysis done on file : FONMVHL2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4258
Alpha (based on Nusselt (Tdel)) = 0.8901
Enhancement (q) = 1.220
Enhancement (Del-T) = 1.161

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.85 | 6.075E+03 | 1.377E+04 | 1.517E+05 | 11.02 | 48.53 |
| 2 | 3.38 | 5.908E+03 | 1.355E+04 | 1.474E+05 | 10.87 | 48.68 |
| 3 | 2.91 | 5.778E+03 | 1.368E+04 | 1.436E+05 | 10.49 | 48.68 |
| 4 | 2.44 | 5.580E+03 | 1.367E+04 | 1.385E+05 | 10.13 | 48.74 |
| 5 | 1.97 | 5.372E+03 | 1.400E+04 | 1.326E+05 | 9.47 | 48.73 |
| 6 | 1.50 | 5.052E+03 | 1.432E+04 | 1.238E+05 | 8.64 | 48.71 |
| 7 | 1.03 | 4.605E+03 | 1.535E+04 | 1.113E+05 | 7.25 | 48.62 |
| 8 | 1.50 | 5.045E+03 | 1.428E+04 | 1.242E+05 | 8.70 | 48.75 |
| 9 | 1.03 | 4.591E+03 | 1.521E+04 | 1.117E+05 | 7.34 | 48.70 |
| 10 | 1.97 | 5.364E+03 | 1.396E+04 | 1.331E+05 | 9.54 | 48.69 |
| 11 | 2.44 | 5.596E+03 | 1.378E+04 | 1.398E+05 | 10.14 | 48.72 |
| 12 | 2.91 | 5.779E+03 | 1.370E+04 | 1.445E+05 | 10.55 | 48.65 |
| 13 | 3.38 | 5.881E+03 | 1.342E+04 | 1.475E+05 | 10.99 | 48.66 |
| 14 | 3.85 | 5.989E+03 | 1.334E+04 | 1.511E+05 | 11.33 | 48.77 |

Least-Squares Line for Ho vs q curve:
Slope = -2.8095E-01
Intercept = 5.8479E+05

Least-squares line for q = a*delta-T^b
a = 2.4663E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVNL2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.8387
Alpha (based on Nusselt (Tdel)) = 0.8688
Enhancement (q) = 1.079
Enhancement (Del-T) = 1.059

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.85 | 5.651E+03 | 1.326E+04 | 1.405E+05 | 10.59 | 48.72 |
| 2 | 3.38 | 5.521E+03 | 1.335E+04 | 1.373E+05 | 10.29 | 48.74 |
| 3 | 2.91 | 5.371E+03 | 1.352E+04 | 1.339E+05 | 9.90 | 48.78 |
| 4 | 2.44 | 5.217E+03 | 1.400E+04 | 1.293E+05 | 9.23 | 48.65 |
| 5 | 1.97 | 4.929E+03 | 1.405E+04 | 1.225E+05 | 8.72 | 48.73 |
| 6 | 1.50 | 4.582E+03 | 1.451E+04 | 1.133E+05 | 7.81 | 48.72 |
| 7 | 1.03 | 4.061E+03 | 1.530E+04 | 9.942E+04 | 6.50 | 48.66 |
| 8 | 1.50 | 4.576E+03 | 1.448E+04 | 1.142E+05 | 7.89 | 48.81 |
| 9 | 1.03 | 4.043E+03 | 1.507E+04 | 9.939E+04 | 6.59 | 48.66 |
| 10 | 1.97 | 4.934E+03 | 1.412E+04 | 1.239E+05 | 8.78 | 48.73 |
| 11 | 2.44 | 5.188E+03 | 1.383E+04 | 1.302E+05 | 9.42 | 48.63 |
| 12 | 2.91 | 5.379E+03 | 1.360E+04 | 1.356E+05 | 9.97 | 48.66 |
| 13 | 3.38 | 5.514E+03 | 1.334E+04 | 1.395E+05 | 10.46 | 48.75 |
| 14 | 3.85 | 5.642E+03 | 1.324E+04 | 1.418E+05 | 10.71 | 48.67 |

Least-Squares Line for Ho vs q curve:
Slope = -2.7734E-01
Intercept = 5.8363E-05

Least-squares line for q = a*delta-T^b
a = 2.4150E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNL2T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRP2KT
Data taken by : O'KEEFE
This analysis done on file : FONMAHL3T2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8352
Alpha (based on Nusselt (Tdel)) = 0.9682
Enhancement (q) = 1.355
Enhancement (Del-T) = 1.256

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 1.03 | 4.880E+03 | 1.461E+04 | 3.506E+05 | 24.00 | 99.94 |
| 2 | 1.49 | 5.280E+03 | 1.378E+04 | 3.824E+05 | 27.75 | 100.01 |
| 3 | 1.96 | 5.597E+03 | 1.371E+04 | 4.070E+05 | 29.67 | 100.00 |
| 4 | 2.43 | 5.783E+03 | 1.345E+04 | 4.219E+05 | 31.35 | 100.04 |
| 5 | 2.90 | 5.940E+03 | 1.337E+04 | 4.337E+05 | 32.45 | 99.99 |
| 6 | 3.36 | 6.009E+03 | 1.305E+04 | 4.397E+05 | 33.70 | 100.02 |
| 7 | 3.83 | 6.100E+03 | 1.297E+04 | 4.465E+05 | 34.42 | 99.99 |
| 8 | 3.36 | 6.014E+03 | 1.307E+04 | 4.388E+05 | 33.57 | 99.90 |
| 9 | 3.83 | 6.100E+03 | 1.297E+04 | 4.460E+05 | 34.38 | 99.95 |
| 10 | 2.90 | 5.939E+03 | 1.336E+04 | 4.326E+05 | 32.39 | 99.93 |
| 11 | 2.43 | 5.783E+03 | 1.344E+04 | 4.210E+05 | 31.32 | 100.07 |
| 12 | 1.96 | 5.597E+03 | 1.370E+04 | 4.060E+05 | 29.64 | 100.08 |
| 13 | 1.49 | 5.278E+03 | 1.375E+04 | 3.811E+05 | 27.73 | 100.04 |
| 14 | 1.03 | 4.883E+03 | 1.459E+04 | 3.492E+05 | 23.93 | 99.96 |

Least-Squares Line for Ho vs q curve:
Slope = -2.2528E-01
Intercept = 7.6980E+05

Least-squares line for q = a*delta-T^b
a = 3.1776E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHL3T2

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRP9&T
Data taken by : O'KEEFE
This analysis done on file : FONMANL3T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2023
Alpha (based on Nusselt (Tdel)) = 0.8330
Enhancement (q) = 1.302
Enhancement (Del-T) = 1.219

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.83 | 5.767E+03 | 1.262E+04 | 4.229E+05 | 33.50 | 99.98 |
| 2 | 3.36 | 5.682E+03 | 1.279E+04 | 4.139E+05 | 32.36 | 99.92 |
| 3 | 2.90 | 5.564E+03 | 1.297E+04 | 4.050E+05 | 31.23 | 100.07 |
| 4 | 2.43 | 5.398E+03 | 1.312E+04 | 3.908E+05 | 29.78 | 99.90 |
| 5 | 1.96 | 5.197E+03 | 1.348E+04 | 3.759E+05 | 27.89 | 100.00 |
| 6 | 1.49 | 4.867E+03 | 1.370E+04 | 3.519E+05 | 25.69 | 100.12 |
| 7 | 1.03 | 4.390E+03 | 1.428E+04 | 3.154E+05 | 22.09 | 100.03 |
| 8 | 1.49 | 4.877E+03 | 1.380E+04 | 3.523E+05 | 25.53 | 99.90 |
| 9 | 1.03 | 4.398E+03 | 1.438E+04 | 3.160E+05 | 21.97 | 99.95 |
| 10 | 1.96 | 5.189E+03 | 1.344E+04 | 3.763E+05 | 28.00 | 99.96 |
| 11 | 2.43 | 5.394E+03 | 1.311E+04 | 3.924E+05 | 29.93 | 100.02 |
| 12 | 2.90 | 5.558E+03 | 1.294E+04 | 4.045E+05 | 31.25 | 99.91 |
| 13 | 3.36 | 5.663E+03 | 1.259E+04 | 4.127E+05 | 32.51 | 99.87 |
| 14 | 3.83 | 5.776E+03 | 1.265E+04 | 4.211E+05 | 33.30 | 100.01 |

Least-Squares Line for Ho vs q curve:
Slope = -2.2956E-01
Intercept = 7.6779E+05

Least-squares line for q = a*delta-T^b
a = 3.0712E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVHL3T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.6094
Alpha (based on Nusselt (Tdel)) = 0.9949
Enhancement (q) = 1.415
Enhancement (Del-T) = 1.297

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 3.84 | 6.544E+03 | 1.581E+04 | 1.570E+05 | 9.93 | 48.61 |
| 2 | 3.37 | 6.381E+03 | 1.565E+04 | 1.526E+05 | 9.75 | 48.70 |
| 3 | 2.90 | 6.240E+03 | 1.580E+04 | 1.481E+05 | 9.38 | 48.68 |
| 4 | 2.43 | 6.057E+03 | 1.598E+04 | 1.425E+05 | 8.91 | 48.60 |
| 5 | 1.97 | 5.839E+03 | 1.645E+04 | 1.370E+05 | 8.33 | 48.69 |
| 6 | 1.50 | 5.451E+03 | 1.649E+04 | 1.268E+05 | 7.69 | 48.65 |
| 7 | 1.03 | 4.959E+03 | 1.761E+04 | 1.151E+05 | 6.54 | 48.75 |
| 8 | 1.50 | 5.441E+03 | 1.642E+04 | 1.271E+05 | 7.74 | 48.62 |
| 9 | 1.03 | 4.961E+03 | 1.764E+04 | 1.146E+05 | 6.50 | 48.63 |
| 10 | 1.97 | 5.781E+03 | 1.603E+04 | 1.367E+05 | 8.53 | 48.65 |
| 11 | 2.43 | 6.023E+03 | 1.577E+04 | 1.431E+05 | 9.07 | 48.62 |
| 12 | 2.90 | 6.221E+03 | 1.568E+04 | 1.483E+05 | 9.45 | 48.65 |
| 13 | 3.37 | 6.393E+03 | 1.572E+04 | 1.529E+05 | 9.73 | 48.67 |
| 14 | 3.84 | 6.490E+03 | 1.549E+04 | 1.554E+05 | 10.03 | 48.74 |

Least-Squares Line for Ho vs q curve:
Slope = -2.3649E-01
Intercept = 5.8263E+05

Least-squares line for q = a*delta-T^b
a = 2.7690E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVNL3T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0410
Alpha (based on Nusselt (Tdel)) = 0.9419
Enhancement (q) = 1.202
Enhancement (Del-T) = 1.148

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 3.37 | 5.954E+03 | 1.506E+04 | 1.438E+05 | 9.55 | 48.73 |
| 2 | 3.84 | 6.043E+03 | 1.469E+04 | 1.462E+05 | 9.95 | 48.77 |
| 3 | 3.37 | 5.937E+03 | 1.494E+04 | 1.424E+05 | 9.53 | 48.67 |
| 4 | 3.84 | 6.031E+03 | 1.461E+04 | 1.443E+05 | 9.87 | 48.59 |
| 5 | 2.90 | 5.754E+03 | 1.493E+04 | 1.373E+05 | 9.20 | 48.69 |
| 6 | 2.43 | 5.565E+03 | 1.523E+04 | 1.330E+05 | 8.73 | 48.74 |
| 7 | 1.97 | 5.292E+03 | 1.543E+04 | 1.254E+05 | 8.13 | 48.63 |
| 8 | 1.50 | 4.917E+03 | 1.576E+04 | 1.158E+05 | 7.35 | 48.68 |
| 9 | 1.03 | 4.397E+03 | 1.686E+04 | 1.032E+05 | 6.12 | 48.73 |
| 10 | 1.50 | 4.940E+03 | 1.602E+04 | 1.172E+05 | 7.31 | 48.72 |
| 11 | 1.03 | 4.393E+03 | 1.682E+04 | 1.032E+05 | 6.13 | 48.72 |
| 12 | 1.97 | 5.295E+03 | 1.548E+04 | 1.265E+05 | 8.17 | 48.67 |
| 13 | 2.44 | 5.561E+03 | 1.522E+04 | 1.334E+05 | 8.77 | 48.61 |
| 14 | 2.90 | 5.771E+03 | 1.507E+04 | 1.388E+05 | 9.21 | 48.66 |

Least-Squares Line for Ho vs q curve:
Slope = -2.5211E-01
Intercept = 5.8301E+05

Least-squares line for q = a*delta-T^b
a = 2.6202E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNL3T1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPC[illegible]
Data taken by : O'KEEFE
This analysis done on file : FONMAHC1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : COPPER
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8085
Alpha (based on Nusselt (Tdel)) = 0.8318
Ennancement (q) = 1.049
Enhancement (Del-T) = 1.037

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 4.31 | 6.736E+03 | 9.034E+03 | 4.860E+05 | 53.80 | 99.89 |
| 2 | 3.78 | 6.667E+03 | 9.157E+03 | 4.792E+05 | 52.33 | 100.04 |
| 3 | 3.25 | 6.574E+03 | 9.307E+03 | 4.697E+05 | 50.47 | 100.02 |
| 4 | 2.73 | 6.427E+03 | 9.463E+03 | 4.576E+05 | 48.35 | 99.97 |
| 5 | 2.20 | 6.207E+03 | 9.636E+03 | 4.405E+05 | 45.72 | 99.99 |
| 6 | 1.68 | 5.880E+03 | 9.868E+03 | 4.160E+05 | 42.16 | 100.03 |
| 7 | 1.15 | 5.439E+03 | 1.049E+04 | 3.803E+05 | 36.24 | 99.99 |
| 8 | 4.30 | 6.855E+03 | 9.234E+03 | 4.898E+05 | 53.04 | 99.94 |
| 9 | 3.77 | 6.785E+03 | 9.358E+03 | 4.794E+05 | 51.23 | 99.88 |
| 10 | 3.25 | 6.684E+03 | 9.498E+03 | 4.689E+05 | 49.37 | 99.96 |
| 11 | 2.72 | 6.501E+03 | 9.564E+03 | 4.541E+05 | 47.39 | 100.03 |
| 12 | 2.20 | 6.290E+03 | 9.787E-03 | 4.380E+05 | 44.75 | 100.11 |
| 13 | 1.67 | 5.971E-03 | 1.005E-04 | 4.128E+05 | 41.07 | 100.05 |
| 14 | 1.15 | 5.504E+03 | 1.065E+04 | 3.783E+05 | 35.53 | 100.04 |
| 15 | 2.20 | 6.310E-03 | 9.845E+03 | 4.402E-05 | 44.72 | 99.94 |
| 16 | 3.25 | 6.682E+03 | 9.491E+03 | 4.686E+05 | 49.37 | 100.05 |
| 17 | 4.29 | 6.869E+03 | 9.235E+03 | 4.825E+05 | 52.26 | 100.12 |

Least-Squares Line for Ho vs q curve:
Slope = -3.4908E-01
Intercept = 7.5868E+05

Least-squares line for q = a*delta-T^b
a = 2.5131E+04
b = 7.5000E-01

NOTE: 17 data points were stored in file FONMAHC1

NOTE: 17 X-Y pairs were stored in data file

```
NOTE: Program name : DRP0K
      Data taken by                : O'KEEFE
      This analysis done on file : FONMANC1
      This analysis includes end-fin effect
      Thermal conductivity       = 385.0 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using no insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)    =  1.2653
Alpha (based on Nusselt (Tdel)) =  0.8158
Ennancement (q)                 =  1.052
Enhancement (Del-T)             =  1.039
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 4.31 | 5.764E+03 | 9.703E+03 | 4.227E+05 | 43.56 | 99.92 |
| 2 | 3.79 | 5.643E+03 | 9.971E+03 | 4.120E+05 | 41.32 | 99.98 |
| 3 | 3.26 | 5.386E+03 | 9.971E+03 | 3.929E+05 | 39.40 | 100.05 |
| 4 | 2.73 | 5.144E+03 | 1.024E+04 | 3.749E+05 | 36.60 | 99.99 |
| 5 | 2.21 | 4.827E+03 | 1.058E+04 | 3.505E+05 | 33.13 | 99.92 |
| 6 | 1.68 | 4.341E+03 | 1.073E+04 | 3.157E+05 | 29.42 | 100.02 |
| 7 | 1.16 | 3.805E+03 | 1.203E+04 | 2.757E+05 | 22.92 | 100.02 |
| 8 | 1.68 | 4.344E+03 | 1.079E+04 | 3.172E+05 | 29.41 | 100.00 |
| 9 | 1.16 | 3.804E+03 | 1.205E+04 | 2.757E+05 | 22.89 | 99.94 |
| 10 | 2.21 | 4.812E+03 | 1.055E+04 | 3.521E+05 | 33.36 | 100.00 |
| 11 | 2.73 | 5.157E+03 | 1.031E+04 | 3.772E+05 | 36.57 | 99.96 |
| 12 | 3.26 | 5.374E+03 | 9.959E+03 | 3.939E+05 | 39.56 | 99.97 |
| 13 | 3.79 | 5.643E+03 | 9.988E+03 | 4.137E+05 | 41.41 | 99.96 |
| 14 | 4.31 | 5.762E+03 | 9.693E+03 | 4.224E+05 | 43.58 | 99.95 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -2.8166E-01
  Intercept   =  7.2938E+05

Least-squares line for q = a*delta-T^b
  a =  2.5317E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMANC1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRP08T
Data taken by : O'KEEFE
This analysis done on file : FONMVHC1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : COPPER
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4815
Alpha (based on Nusselt (Tdel)) = 0.8379
Enhancement (q) = .958
Enhancement (Del-T) = .968

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 4.32 | 7.579E+03 | 1.110E+04 | 1.749E+05 | 15.75 | 48.74 |
| 2 | 3.79 | 7.327E+03 | 1.098E+04 | 1.683E+05 | 15.32 | 46.69 |
| 3 | 3.26 | 7.140E+03 | 1.110E+04 | 1.631E+05 | 14.69 | 48.63 |
| 4 | 2.74 | 6.907E+03 | 1.128E+04 | 1.575E+05 | 13.96 | 43.63 |
| 5 | 2.21 | 6.573E+03 | 1.144E+04 | 1.492E+05 | 13.04 | 46.63 |
| 6 | 1.68 | 6.158E+03 | 1.185E+04 | 1.399E+05 | 11.81 | 46.72 |
| 7 | 1.16 | 5.538E+03 | 1.251E+04 | 1.249E+05 | 9.90 | 48.73 |

Least-Squares Line for Ho vs q curve:
Slope = -3.2813E-01
Intercept = 5.5448E+05

Least-squares line for q = a*delta-T^b
a = 2.1921E+04
b = 7.5000E-01

NOTE: 07 data points were stored in file FONMVHC1

NOTE: 07 X-Y pairs were stored in data file

NOTE: Program name : DR[illegible]
Data taken by : O'KEEFE
This analysis done on file : FONMVNC1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : COPPER
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0847
Alpha (based on Nusselt (Tdel)) = 0.8663
Enhancement (q) = .942
Enhancement (Del-T) = .956

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 4.32 | 6.182E+03 | 1.238E+04 | 1.461E+05 | 11.80 | 48.53 |
| 2 | 3.79 | 5.937E+03 | 1.255E+04 | 1.401E+05 | 11.16 | 48.64 |
| 3 | 3.27 | 5.646E+03 | 1.277E+04 | 1.336E+05 | 10.48 | 48.77 |
| 4 | 2.74 | 5.290E+03 | 1.301E+04 | 1.252E+05 | 9.63 | 48.79 |
| 5 | 2.21 | 4.865E+03 | 1.339E+04 | 1.144E+05 | 8.54 | 48.71 |
| 6 | 1.68 | 4.309E+03 | 1.379E+04 | 1.009E+05 | 7.32 | 48.64 |
| 7 | 1.16 | 3.641E+03 | 1.540E+04 | 8.492E+04 | 5.51 | 48.62 |
| 8 | 1.68 | 4.323E+03 | 1.399E+04 | 1.023E+05 | 7.31 | 48.67 |
| 9 | 1.16 | 3.537E+03 | 1.533E+04 | 9.518E+04 | 5.56 | 48.73 |
| 10 | 2.21 | 4.811E+03 | 1.306E+04 | 1.151E+05 | 8.82 | 48.74 |
| 11 | 2.74 | 5.290E+03 | 1.305E+04 | 1.264E+05 | 9.68 | 48.68 |
| 12 | 3.27 | 5.637E+03 | 1.276E+04 | 1.353E+05 | 10.60 | 48.75 |
| 13 | 3.79 | 5.915E+03 | 1.248E+04 | 1.408E+05 | 11.28 | 48.59 |
| 14 | 4.32 | 6.185E+03 | 1.240E+04 | 1.470E+05 | 11.85 | 48.64 |

Least-Squares Line for Ho vs q curve:
Slope = -2.7240E-01
Intercept = 5.4643E+05

Least-squares line for q = a*delta-T^b
a = 2.2994E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNC1

NOTE: 14 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMAH68C1
      This analysis includes end-fin effect
      Thermal conductivity       = 385.0 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)       =  2.8065
Alpha (based on Nusselt (Tdel)) =  1.2643
Enhancement (q)                    =  1.934
Enhancement (Del-T)                =  1.640
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 4.29 | 9.492E+03 | 1.466E+04 | 6.577E+05 | 44.87 | 100.04 |
| 2 | 3.76 | 9.328E+03 | 1.488E+04 | 6.388E+05 | 42.93 | 99.97 |
| 3 | 3.24 | 9.132E+03 | 1.522E+04 | 6.213E+05 | 40.83 | 99.96 |
| 4 | 2.72 | 8.827E+03 | 1.553E+04 | 5.975E+05 | 38.48 | 99.92 |
| 5 | 2.19 | 8.375E+03 | 1.581E+04 | 5.666E+05 | 35.84 | 100.01 |
| 6 | 1.67 | 7.795E+03 | 1.637E+04 | 5.249E+05 | 32.06 | 100.02 |
| 7 | 1.15 | 6.985E+03 | 1.771E+04 | 4.679E+05 | 26.42 | 100.07 |
| 8 | 1.67 | 7.804E+03 | 1.647E+04 | 5.292E+05 | 32.13 | 100.00 |
| 9 | 1.15 | 6.992E+03 | 1.776E+04 | 4.684E+05 | 26.37 | 100.08 |
| 10 | 2.20 | 8.478E+03 | 1.623E+04 | 5.785E+05 | 35.64 | 100.01 |
| 11 | 2.72 | 8.949E+03 | 1.593E+04 | 6.088E+05 | 38.21 | 99.92 |
| 12 | 3.24 | 9.254E+03 | 1.559E+04 | 6.313E+05 | 40.50 | 100.01 |
| 13 | 3.76 | 9.531E+03 | 1.537E+04 | 6.466E+05 | 42.06 | 99.95 |
| 14 | 4.28 | 9.743E+03 | 1.520E+04 | 6.612E+05 | 43.50 | 99.97 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -1.9114E-01
  Intercept  =  7.3487E+05

Least-squares line for q = a*delta-T^b
  a =  3.9079E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMAH68C1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN68C1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : COPPER
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.2431
Alpha (based on Nusselt (Tdel)) = 1.3159
Enhancement (q) = 2.059
Enhancement (Del-T) = 1.719

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 4.29 | 7.797E+03 | 1.712E+04 | 5.462E+05 | 31.90 | 100.00 |
| 2 | 3.77 | 7.478E+03 | 1.747E+04 | 5.242E+05 | 30.00 | 100.03 |
| 3 | 3.25 | 7.128E+03 | 1.807E+04 | 4.989E+05 | 27.61 | 99.95 |
| 4 | 2.72 | 6.596E+03 | 1.812E+04 | 4.635E+05 | 25.58 | 99.99 |
| 5 | 2.20 | 5.980E+03 | 1.823E+04 | 4.200E+05 | 23.05 | 100.02 |
| 6 | 1.68 | 5.287E+03 | 1.914E+04 | 3.723E+05 | 19.45 | 100.04 |
| 7 | 1.15 | 4.502E+03 | 2.354E+04 | 3.170E+05 | 13.47 | 100.10 |
| 8 | 1.68 | 5.263E+03 | 1.901E+04 | 3.730E+05 | 19.62 | 100.01 |
| 9 | 1.15 | 4.450E+03 | 2.252E+04 | 3.153E+05 | 14.00 | 100.04 |
| 10 | 2.20 | 6.006E+03 | 1.874E+04 | 4.275E+05 | 22.81 | 99.95 |
| 11 | 2.73 | 6.655E+03 | 1.877E+04 | 4.724E+05 | 25.17 | 99.88 |
| 12 | 3.25 | 7.209E+03 | 1.878E+04 | 5.113E+05 | 27.23 | 99.99 |
| 13 | 3.77 | 7.658E+03 | 1.862E+04 | 5.423E+05 | 29.12 | 99.97 |
| 14 | 4.30 | 8.034E+03 | 1.837E+04 | 5.663E+05 | 30.83 | 100.02 |

Least-Squares Line for Ho vs q curve:
Slope = -1.3433E-01
Intercept = 7.1006E+05

Least-squares line for q = a*delta-T^b
a = 4.1757E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN68C1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
      Data taken by                  : O'KEEFE
      This analysis done on file : FONMVH68C1
      This analysis includes end-fin effect
      Thermal conductivity       = 385.0 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient   = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement   : WIRE-WRAPPED SMOOTH TUBE
      Tube material      : COPPER
      Pressure condition : VACUUM
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)    =  2.5490
Alpha (based on Nusselt (Tdel)) =  1.1854
Enhancement (q)                 =  1.787
Enhancement (Del-T)             =  1.546

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 4.32 | 9.811E+03 | 1.641E+04 | 2.246E+05 | 13.69 | 48.74 |
| 2 | 3.79 | 9.448E+03 | 1.628E+04 | 2.148E+05 | 13.19 | 48.81 |
| 3 | 3.26 | 9.165E+03 | 1.658E+04 | 2.062E+05 | 12.43 | 48.78 |
| 4 | 2.73 | 8.699E+03 | 1.660E+04 | 1.946E+05 | 11.72 | 48.77 |
| 5 | 2.21 | 8.209E+03 | 1.703E+04 | 1.826E+05 | 10.72 | 48.72 |
| 6 | 1.68 | 7.523E+03 | 1.755E+04 | 1.668E+05 | 9.51 | 48.76 |
| 7 | 1.15 | 6.670E+03 | 1.944E+04 | 1.451E+05 | 7.46 | 48.62 |
| 8 | 1.68 | 7.515E+03 | 1.754E+04 | 1.687E+05 | 9.62 | 48.91 |
| 9 | 1.15 | 6.668E+03 | 1.946E+04 | 1.455E+05 | 7.48 | 48.55 |
| 10 | 2.21 | 8.220E+03 | 1.713E+04 | 1.848E+05 | 10.79 | 48.53 |
| 11 | 2.74 | 8.740E+03 | 1.678E+04 | 1.968E+05 | 11.73 | 48.59 |
| 12 | 3.26 | 9.189E+03 | 1.668E+04 | 2.073E+05 | 12.43 | 48.63 |
| 13 | 3.79 | 9.446E+03 | 1.627E+04 | 2.139E+05 | 13.15 | 48.74 |
| 14 | 4.31 | 9.846E+03 | 1.649E+04 | 2.212E+05 | 13.42 | 48.60 |

Least-Squares Line for Ho vs q curve:
  Slope      = -2.0791E-01
  Intercept  =  5.4980E+05

Least-squares line for q = a*delta-T^b
  a =  3.1228E+04
  b =  7.5000E-01

NOTE: 14 data points were stored in file FONMVH68C1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVN68C1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : COPPER
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0378
Alpha (based on Nusselt (Tdel)) = 1.2885
Enhancement (q) = 1.825
Enhancement (Del-T) = 1.570

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 4.32 | 7.410E+03 | 1.958E+04 | 1.749E+05 | 8.93 | 48.82 |
| 2 | 3.79 | 7.037E+03 | 1.994E+04 | 1.644E+05 | 8.24 | 48.70 |
| 3 | 3.26 | 6.671E+03 | 2.102E+04 | 1.549E+05 | 7.37 | 48.66 |
| 4 | 2.74 | 6.177E+03 | 2.189E+04 | 1.432E+05 | 6.54 | 48.63 |
| 5 | 2.21 | 5.557E+03 | 2.262E+04 | 1.288E+05 | 5.69 | 48.61 |
| 6 | 1.68 | 4.800E+03 | 2.340E+04 | 1.111E+05 | 4.75 | 48.60 |
| 7 | 1.16 | 3.882E+03 | 2.496E+04 | 8.997E+04 | 3.60 | 48.78 |
| 8 | 1.68 | 4.765E+03 | 2.277E+04 | 1.127E+05 | 4.95 | 48.81 |
| 9 | 1.16 | 3.877E+03 | 2.492E+04 | 8.988E+04 | 3.61 | 48.63 |
| 10 | 2.21 | 5.572E+03 | 2.308E+04 | 1.316E+05 | 5.70 | 48.67 |
| 11 | 2.74 | 6.155E+03 | 2.177E+04 | 1.446E+05 | 6.64 | 48.55 |
| 12 | 3.27 | 6.643E+03 | 2.086E+04 | 1.567E+05 | 7.51 | 48.66 |
| 13 | 3.79 | 7.016E+03 | 1.981E+04 | 1.647E+05 | 8.31 | 48.67 |
| 14 | 4.32 | 7.407E+03 | 1.954E+04 | 1.746E+05 | 8.94 | 48.85 |
| 15 | 2.74 | 6.165E+03 | 2.172E+04 | 1.423E+05 | 6.55 | 48.58 |
| 16 | 1.16 | 3.896E+03 | 2.523E+04 | 8.882E+04 | 3.52 | 48.70 |

Least-Squares Line for Ho vs q curve:
Slope = -1.6323E-01
Intercept = 5.4549E+05

Least-squares line for q = a*delta-T^b
a = 3.4454E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVN68C1

NOTE: 16 X-Y pairs were stored in data file

```
NOTE: Program name : DRPOK
      Data taken by                 : O'KEEFE
      This analysis done on file : FONMAH71C1
      This analysis includes end-fin effect
      Thermal conductivity       = 385.0 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using HEATEX insert inside tube
      Tube Enhancement    : SMOOTH TUBE
      Tube material       : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  3.0634
Alpha (based on Nusselt (Tdel))   =  1.5049
Enhancement (q)                   =  2.313
Enhancement (Del-T)               =  1.875
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C |
|---|---|---|---|---|---|---|
| 1 | 4.29 | 1.097E+04 | 1.770E+04 | 7.469E+05 | 42.20 | 99.96 |
| 2 | 3.76 | 1.075E+04 | 1.796E+04 | 7.258E+05 | 40.42 | 99.96 |
| 3 | 3.24 | 1.050E+04 | 1.835E+04 | 7.052E+05 | 38.42 | 99.99 |
| 4 | 2.72 | 1.007E+04 | 1.860E+04 | 6.764E+05 | 36.37 | 99.97 |
| 5 | 2.19 | 9.574E+03 | 1.911E+04 | 6.407E+05 | 33.53 | 99.94 |
| 6 | 1.67 | 8.871E+03 | 1.986E+04 | 5.945E+05 | 29.94 | 100.00 |
| 7 | 1.15 | 7.842E+03 | 2.121E+04 | 5.237E+05 | 24.63 | 99.94 |
| 8 | 1.67 | 8.896E+03 | 2.011E+04 | 6.029E+05 | 29.97 | 99.92 |
| 9 | 1.15 | 7.902E+03 | 2.174E+04 | 5.310E+05 | 24.43 | 100.03 |
| 10 | 2.20 | 9.801E+03 | 2.017E+04 | 6.671E+05 | 33.06 | 100.00 |
| 11 | 2.72 | 1.039E+04 | 1.979E+04 | 7.079E+05 | 35.77 | 99.96 |
| 12 | 3.24 | 1.090E+04 | 1.970E+04 | 7.425E+05 | 37.63 | 100.07 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -1.4745E-01
  Intercept   =  7.2637E+05

Least-squares line for q = a*delta-T^b
  a =  4.6353E+04
  b =  7.5000E-01


NOTE: 12 data points were stored in file FONMAH71C1

NOTE: 12 X-Y pairs were stored in data file
```

```
NOTE: Program name : DRPOK
      Data taken by                : O'KEEFE
      This analysis done on file : FONMAN71C1
      This analysis includes end-fin effect
      Thermal conductivity       = 385.0 (W/m.K)
      Inside diameter, Di        = 12.70 (mm)
      Outside diameter, Do       = 19.05 (mm)
      This analysis uses the QUARTZ THERMOMETER readings
      Modified Petukhov-Popov coefficient    = 1.0000
      Using no insert inside tube
      Tube Enhancement    : WIRE-WRAPPED SMOOTH TUBE
      Tube material       : COPPER
      Pressure condition : ATMOSPHERIC
      Nusselt theory is used for Ho

Ci (based on Petukhov-Popov)      =  1.2563
Alpha (based on Nusselt (Tdel)) =  1.7215
Enhancement (q)                   =  2.847
Enhancement (Del-T)               =  2.132
```

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 4.29 | 8.928E+03 | 2.330E+04 | 6.214E+05 | 25.67 | 99.87 |
| 2 | 3.77 | 8.523E+03 | 2.393E+04 | 5.926E+05 | 24.77 | 100.01 |
| 3 | 3.25 | 8.042E+03 | 2.471E+04 | 5.581E+05 | 22.59 | 99.93 |
| 4 | 2.72 | 7.374E+03 | 2.471E+04 | 5.131E+05 | 20.77 | 99.94 |
| 5 | 2.20 | 6.613E+03 | 2.490E+04 | 4.625E+05 | 18.57 | 100.05 |
| 6 | 1.68 | 5.750E+03 | 2.592E+04 | 4.028E+05 | 15.54 | 99.99 |
| 7 | 1.15 | 4.766E+03 | 3.095E+04 | 3.333E+05 | 10.77 | 99.95 |
| 8 | 1.68 | 5.724E+03 | 2.582E+04 | 4.054E+05 | 15.70 | 100.09 |
| 9 | 1.15 | 4.874E+03 | 3.643E+04 | 3.424E+05 | 9.40 | 100.10 |
| 10 | 2.20 | 6.658E+03 | 2.605E+04 | 4.720E+05 | 18.12 | 100.04 |
| 11 | 2.73 | 7.500E+03 | 2.659E+04 | 5.292E+05 | 19.90 | 100.03 |
| 12 | 3.25 | 8.213E+03 | 2.671E+04 | 5.778E+05 | 21.64 | 100.10 |
| 13 | 3.77 | 8.881E+03 | 2.713E+04 | 6.202E+05 | 22.86 | 99.89 |
| 14 | 4.29 | 9.435E+03 | 2.704E+04 | 6.561E+05 | 24.27 | 99.99 |

```
Least-Squares Line for Ho vs q curve:
  Slope       = -8.6527E-02
  Intercept   =  7.0340E+05

Least-squares line for q = a*delta-T^b
  a =  5.5185E+04
  b =  7.5000E-01


NOTE: 14 data points were stored in file FONMAN71C1

NOTE: 14 X-Y pairs were stored in data file
```

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVN71C1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : COPPER
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0883
Alpha (based on Nusselt (Tdel)) = 1.4135
Enhancement (q) = 1.809
Enhancement (Del-T) = 1.560

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | T (C |
|---|---|---|---|---|---|---|
| 1 | 4.32 | 7.865E+03 | 2.150E+04 | 1.844E+05 | 8.58 | 48.5 |
| 2 | 3.79 | 7.432E+03 | 2.168E+04 | 1.751E+05 | 8.07 | 48.7 |
| 3 | 3.26 | 7.045E+03 | 2.292E+04 | 1.647E+05 | 7.18 | 48.7 |
| 4 | 2.74 | 6.532E+03 | 2.410E+04 | 1.529E+05 | 6.35 | 48.7 |
| 5 | 2.21 | 5.872E+03 | 2.512E+04 | 1.376E+05 | 5.48 | 48.6 |
| 6 | 1.68 | 5.029E+03 | 2.523E+04 | 1.187E+05 | 4.70 | 48.7 |
| 7 | 1.16 | 4.068E+03 | 2.738E+04 | 9.574E+04 | 3.50 | 48.7 |
| 8 | 1.68 | 5.056E+03 | 2.616E+04 | 1.204E+05 | 4.60 | 48.5 |
| 9 | 1.16 | 4.073E+03 | 2.775E+04 | 9.599E+04 | 3.46 | 48.6 |
| 10 | 2.21 | 5.881E+03 | 2.559E+04 | 1.402E+05 | 5.48 | 48.5 |
| 11 | 2.74 | 6.521E+03 | 2.427E+04 | 1.563E+05 | 6.44 | 48.6 |
| 12 | 3.27 | 7.074E+03 | 2.350E+04 | 1.693E+05 | 7.21 | 48.6 |
| 13 | 3.79 | 7.497E+03 | 2.238E+04 | 1.802E+05 | 8.05 | 48.9 |
| 14 | 4.32 | 7.370E+03 | 2.160E+04 | 1.882E+05 | 8.71 | 48.3 |

Least-Squares Line for Ho vs q curve:
Slope = -1.4850E-01
Intercept = 5.4553E+05

Least-squares line for q = a*delta-T^b
a = 3.7811E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN71C1

NOTE: 14 X-Y pairs were stored in data file

NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVH71C2
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : COPPER
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.7647
Alpha (based on Nusselt (Tdel)) = 1.2803
Enhancement (q) = 1.686
Enhancement (Del-T) = 1.479

| Data # | Vw (m/s) | Uo (W/m^2-K) | Ho (W/m^2-K) | Qp (W/m^2) | Tcf (C) | Ts (C) |
|---|---|---|---|---|---|---|
| 1 | 1.16 | 7.118E+03 | 2.072E+04 | 1.583E+05 | 7.64 | 48.64 |
| 2 | 1.68 | 8.035E+03 | 1.882E+04 | 1.832E+05 | 9.73 | 48.77 |
| 3 | 2.21 | 8.775E+03 | 1.833E+04 | 2.015E+05 | 10.99 | 48.69 |
| 4 | 2.74 | 9.287E+03 | 1.784E+04 | 2.147E+05 | 12.03 | 48.73 |
| 5 | 3.26 | 9.855E+03 | 1.805E+04 | 2.262E+05 | 12.53 | 48.55 |
| 6 | 3.79 | 1.015E+04 | 1.766E+04 | 2.354E+05 | 13.33 | 48.75 |
| 7 | 4.32 | 1.038E+04 | 1.736E+04 | 2.413E+05 | 13.90 | 48.79 |
| 8 | 3.26 | 9.850E+03 | 1.802E+04 | 2.245E+05 | 12.46 | 48.60 |
| 9 | 2.21 | 8.857E+03 | 1.865E+04 | 1.992E+05 | 10.68 | 48.55 |
| 10 | 1.16 | 7.142E+03 | 2.088E+04 | 1.571E+05 | 7.53 | 48.57 |

Least-Squares Line for Ho vs q curve:
Slope = -1.9477E-01
Intercept = 5.5020E+05

Least-squares line for q = a*delta-T^b
a = 3.3765E+04
b = 7.5000E-01

NOTE: 10 data points were stored in file FONMVH71C2

NOTE: 10 X-Y pairs were stored in data file

# APPENDIX E. DRPOK PROGRAM LISTING

The program DRPOK, which was used to collect and reprocess all of the data, is listed in this appendix.

```
100! DRPOK (O'KEEFE)
106! REVISED FROM DRP12B:   JUL 1992 (S. MEMORY)
107!
08! TO BE USED WITH NON-INSTRUMENTED TUBES ONLY
09! TAKES DATA IN THE FORMAT OF SWENSEN/O'KEEFE
10! CAN REPROCESS ANY NON-INSTRUMENTED DATA
12!
13! THIS PROGRAM WAS USED TO COLLECT ALL THE NON-
14! INSTRUMENTED DATA TAKEN BY O'KEEFE (APR-SEP 1992) FOR TITANIUM TUBES
15!
17!    MEANING OF ALL FLAGS IN PROGRAM
18!
19!    IFT:   FLUID TYPE
20!    ISO:   OPTION WITHIN PROGRAM
21!    IM:    INPUT MODE
22!    IWIL:  VALUE OF C1 USED
23!    IFG:   FINNED OR SMOOTH
24!    INN:   INSERT TYPE
25!    IWT:   LOOP NO. WITHIN PROGRAM
26!    IWTH:  ALTERNATIVE CONDENSER TUBES
027!    IMC:   TUBE MATERIAL
028!    ITDS:  TUBE DIAMETER
029!    IPC:   PRESSURE CONDITION
030!    INF:   DIMENSIONLESS FILE REQUIRED
031!    IPF:   PLOT FILE REQUIRED
032!    IOV:   OUTPUT REQUIRED
033!    IHI:   INSIDE HTC CORRELATION
034!    IOC:   OUTSIDE HTC THEORY/CORRELATION
035  COM /Cc/ C(7)
036  COM /Cc55/ T55(5)
037  COM /Cc56/ T56(5)
038  COM /Cc57/ T57(5)
039  COM /Cc58/ T58(5)
040  COM /Fld/ Ift,Istu
041  DIM Emf(20),Tw(6)
042  COM /Pr/ Qpa(20),Tfm(20),Tfmr,Ipc,Opr
043  COM /Wil/ Nrun,Itm,Iwth,Imc,Ife,Ijob,Iwd,Ifg,Ipco,Ifto,Iwil,Ihi,Ioc,Inam,H
u,Rexp,Rm
044  COM /Geom/ D1,D2,Di,Do,L,L1,L2
046  DATA 0.10086091,25727.94369,-767345.8295,78025595.81
047  DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
048  READ C(*)
049  DATA 273.15,2.5943E-2,-7.2671E-7,3.2941E-11,-9.7719E-16,9.7121E-20
050  READ T55(*)
051  DATA 273.15,2.5878E-2,-5.9853E-7,-3.1242E-11,1.3275E-14,-1.0188E-18
052  READ T56(*)
053  DATA 273.15,2.5923E-2,-7.3933E-7,2.8625E-11,1.9717E-15,-2.2486E-19
```

```
1054  READ T57(*)
1055  DATA 273.15,2.5931E-2,-7.5232E-7,4.0657E-11,-1.2791E-15,6.4402E-20
1056  READ T58(*)
1057  Dr=.015875    ! Outside diameter of the outlet end
1058  Dssp=.1524    ! Inside diameter of stainless steel test section
1059  Ax=PI*Dssp^2/4
1060  Alp2=0.
1061  L=.13335      ! Condensing length
1062  L1=.060325    ! Inlet end "fin length"
1063  L2=.034925    ! Outlet end "fin length"
1064  PRINTER IS 1
1065  BEEP
1066  PRINT USING "4X,""Select option:"""
1069  PRINT USING "6X,"" 0 Take data or re-process previous data"""
1084  PRINT USING "6X,"" 1 Print raw data"""
1090  PRINT USING "6X,"" 2 WILSON Analysys"""
1093  PRINT USING "6X,"" 3 MODIFY"""
1096  PRINT USING "6X,"" 4 PURGE"""
1102  PRINT USING "6X,"" 5 RENAME"""
1105  INPUT Iso
1108  Iso=Iso+1
1111  IF Iso>1 THEN 3094
1112  BEEP
1115  INPUT "SELECT FLUID (0=WATER, 1=R-113, 2=EG)",Ift
1116  Ifto=Ift
1117  BEEP
1118  Ijob=0
1119  INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
1120  Im=Im+1
1123  BEEP
1124  IF Im=1 THEN
1126  INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
1129  OUTPUT 709;"TD";Date$
1132  OUTPUT 709;"TD"
1133  ENTER 709;Date$
1135  END IF
1136  IF Ijob=1 THEN
1138  BEEP
1141  INPUT "SKIP PAGE AND HIT ENTER",Ol
1144  END IF
1145  PRINTER IS 701
1146  IF Im=1 THEN
1148  ENTER 709;Date$
1150  PRINT "           Month, date and time :";Date$
1151  END IF
1153  PRINT
```

```
156  PRINT USING "10X,""NOTE: Program name : DRPOK"""
171  IF Ijob=1 THEN 1189
74   BEEP
86   INPUT "SELECT (Ci:0=FIND,1=STORED Ci)",Iwil
189  IF Im=1 THEN
92   BEEP
95   INPUT "GIVE A NAME FOR THE RAW DATA FILE",D_file$
98   PRINT USING "16X,""File name     : "",14A";D_file$
01   CREATE BDAT D_file$,30
04   ASSIGN @File TO D_file$
07   BEEP
10   INPUT "ENTER GEOMETRY CODE (1=FINNED,0=PLAIN)",Ifg
11   Inn=0
12   PRINTER IS 1
16   BEEP
17   PRINT "   ENTER INSERT TYPE:"
18   PRINT "       0=NONE (DEFAULT)"
19   PRINT "       1=TWISTED TAPE"
220  PRINT "       2=WIRE WRAP"
221  PRINT "       3=HEATEX"
222  INPUT Inn
226  OUTPUT @File;Ifg,Inn
227  Iwt=0  ! FOR UNINSTRUMENTED TUBE
228  Fh=0
231  Fp=0
234  Fw=0
235  Istu=0
237  IF Ifg=0 THEN 1241
238  INPUT "FIN PITCH, HEIGHT AND WIDTH, Fp,Fh,Fw",Fp,Fh,Fw
241  OUTPUT @File;Iwt,Fp,Fw,Fh
242  ELSE
249  BEEP
250  PRINTER IS 1
252  PRINT "  STUDENT'S DATA TO BE REPROCESSED:"
253  PRINT "  0=SWENSEN/O'KEEFE  (DEFAULT)"
254  PRINT "  1=VAN PETTEN/MITROU/COUMES/GUTTENDORF"
255  INPUT Istu
256  BEEP
257  PRINT
259  IF Istu=1 THEN
260  PRINT " STUDENT NAME:"
261  PRINT " 0=VAN PETTEN"
262  PRINT " 1=MITROU"
263  PRINT " 2=COUMES"
264  PRINT " 3=GUTTENDORF"
265  ELSE
```

```
1267  PRINT " 4=SWENSEN"
1268  PRINT " 5=O'KEEFE"
1271  END IF
1272  INPUT Inam
1273  BEEP
1274  INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D_file$
1275  PRINTER IS 701
1276  IF Inam=0 THEN PRINT USING "16X,""Data taken by            : VAN PETTE
""
1277  IF Inam=1 THEN PRINT USING "16X,""Data taken by            : MITROU"""
1278  IF Inam=2 THEN PRINT USING "16X,""Data taken by            : COUMES"""
1279  IF Inam=3 THEN PRINT USING "16X,""Data taken by            : GUTTENDORF
""
1280  IF Inam=4 THEN PRINT USING "16X,""Data taken by            : SWENSEN"""
1281  IF Inam=5 THEN PRINT USING "16X,""Data taken by            : O'KEEFE"""
1282  PRINT USING "16X,""This analysis done on file : "",10A";D_file$
1283  PRINTER IS 1
1285  BEEP
1286  INPUT "ENTER NUMBER OF DATA SETS STORED",Nrun
1287  ASSIGN @File TO D_file$
1288  ENTER @File;Ifg,Inn
1289  IF Istu=0 THEN
1290  ENTER @File;Iwt,Fp,Fw,Fh
1291  ELSE
1292  IF Ifg=0 THEN ENTER @File;Iwt
1293  IF Ifg=1 THEN ENTER @File;Fp,Fw,Fh
1294  END IF
1295  END IF
1296  IF Ijob=1 THEN 1537
1297  IF Ift<>0 THEN 1345
1298  BEEP
1299  PRINTER IS 1
1300  PRINT USING "4X,""Select tube type:"""
1301  PRINT USING "6X,""0 Thick wall Copper"""
1306  PRINT USING "6X,""1 Wolverine Korodense LPD Titanium Tube"""
1320  PRINT USING "6X,""2 Smooth Titanium Tube"""
1321  INPUT Iwth
1322  BEEP
1324  PRINT USING "4X,""Select tube Enhancement used:"""
1325  PRINT USING "6X,""0 SMOOTH TUBE"""
1326  PRINT USING "6X,""1 FINNED TUBE"""
1327  PRINT USING "6X,""2 WIRE-WRAPPED SMOOTH TUBE"""
1328  PRINT USING "6X,""3 LPD KORODENSE TUBE"""
1329  PRINT USING "6X,""4 WIRE-WRAPPED LPD KORODENSE TUBE"""
1330  INPUT Ityp
1331  PRINTER IS 701
```

```
132  BEEP
133  PRINTER IS 1
134  PRINT USING "4X,""Select Material Code:"""
136  PRINT USING "6X,""0 Copper    1 Stainless steel"""
139  PRINT USING "6X,""2 Aluminum  3 90:10 Cu-Ni"""
140  PRINT USING "6X,""4 Titanium """
142  INPUT Imc
145  PRINTER IS 1
148  BEEP
149  Itds=1
351  IF Iwth=0 THEN
352  PRINT USING "4X,""SELECT TUBE DIA TYPE:"""
357  PRINT USING "6X,""0  SMALL"""
360  PRINT USING "6X,""1  MEDIUM (DEFAULT)"""
363  PRINT USING "6X,""2  LARGE"""
366  INPUT Itds
367  END IF
369  PRINTER IS 701
372  IF Iwth=0 THEN
375  Di=.0127       ! ID OF MEDIUM AND LARGE TUBES
378  Do=.01905      ! OD OF MEDIUM TUBE
383  END IF
384  IF Iwth=1 THEN
399  Di=.01347
402  Do=.01585
405  END IF
457  IF Iwth=2 THEN
458  Do=.01585
459  Di=.01386
460  END IF
461  D1=.01905
462  D2=.01587
465  IF Itds=0 THEN
468     Do=.0127
471     Di=.009525
474  END IF
477  IF Itds=2 THEN Do=.025
478  IF Iwth=1 THEN D1=.01585
479  IF Iwth=1 THEN D2=.01585
484  IF Iwth=2 THEN D1=.01587
485  IF Iwth=2 THEN D2=.01587
487  IF Imc=0 THEN Kcu=385
489  IF Imc=1 THEN Kcu=16
492  IF Imc=2 THEN Kcu=167
495  IF Imc=3 THEN Kcu=45
496  IF Imc=4 THEN Kcu=20.1
```

```
1498  Rm=Do*LOG(Do/Di)/(2*Kcu) ! Wall resistance based on outside area
1501  BEEP
1504  INPUT "ENTER PRESSURE CONDITION (0=V,1=A)",Ipc
1507  Ipco=Ipc
1508  Inf=0
1510  BEEP
1537  Ife=1
1538  PRINTER IS 701
1543  PRINT USING "16X,""This analysis includes end-fin effect"""
1546  PRINT USING "16X,""Thermal conductivity       = "",3D.D,"" (W/m.K)""";Kcu
1549  PRINT USING "16X,""Inside diameter, Di        = "",DD.DD,"" (mm)""";Di*10(
1552  PRINT USING "16X,""Outside diameter, Do       = "",DD.DD,"" (mm)""";Do*10(
1555! BEEP
1556  Ihi=0
1557  PRINTER IS 1
1558  PRINT "    SELECT INSIDE CORRELATION:"
1559  PRINT "        0=SIEDER-TATE (DEFAULT)"
1560  PRINT "        1=SLEICHER-ROUSE"
1561  PRINT "        2=PETUKHOV-POPOV"
1562  INPUT Ihi
1563  IF Ihi=0 THEN
1564  BEEP
1566  INPUT "    SELECT REYNOLDS EXPONENT",Rexp
1567  END IF
1568  Ioc=0
1569  BEEP
1570  PRINT
1571  PRINT "    SELECT OUTSIDE THEORY/CORRELATION FOR WILSON ANALYSIS:"
1572  PRINT "        0=NUSSELT THEORY (DEFAULT)"
1573  PRINT "        1=FUJII (1979) CORRELATION"
1574  INPUT Ioc
1575  BEEP
1576  Itm=1
1577  PRINT
1578  PRINT "    SELECT COOLANT TEMPERATURE RISE MEASUREMENT:"
1579  IF Istu=0 THEN PRINT "        0=SINGLE TEFLON T/C"
1580  PRINT "        1=QUARTZ THERMOMETER (DEFAULT)"
1581  PRINT "        2=10-JUNCTION THERMOPILE"
1582  INPUT Itm
1583  PRINTER IS 701
1584  IF Itm=0 THEN PRINT USING "16X,""This analysis uses the SINGLE TEFLON T/C
readings"""
1585  IF Itm=1 THEN PRINT USING "16X,""This analysis uses the QUARTZ THERMOMETE
 readings"""
1586  IF Itm=2 THEN PRINT USING "16X,""This analysis uses the 10-JUNCTION THERM
PILE readings"""
1587  Iic=1 ! FOR MODIFIED WILSON
1588  IF Ihi=0 THEN Ci=.027
1589! IF Inn=2 AND Di=.009525 THEN Ci=.051  !TO BE MODIFIED
1590! IF Inn=2 AND Di=.0127 THEN Ci=.052
1591! IF Inn=3 THEN Ci=.22
```

```
1592! IF Inn=0 THEN C1=.012
1593! IF Ift=2 THEN C1=.035
1594! END IF
1595  IF Ihi=1 THEN C1=1.
1596  IF Ihi=2 THEN C1=1.
1597  IF Iwil=1 THEN
1598  BEEP
1599  INPUT "ENTER C1 IF DIFFERENT FROM STORED VALUE",C1
1600  END IF
1601  PRINTER IS 701
1602  IF Ihi=0 THEN PRINT USING "16X,""Modified Sieder-Tate coefficient   = "",Z
.4D";C1
1603  IF Ihi=0 THEN PRINT USING "16X,""Chosen Reynolds No. exponent        = "",D
.DD";Rexp
1604  IF Ihi=1 THEN PRINT USING "16X,""Modified Sleicher-Rouse coefficient   = "
,Z.4D";C1
1605  IF Ihi=2 THEN PRINT USING "16X,""Modified Petukhov-Popov coefficient   = "
,Z.4D";C1
1606  IF Inn=0 THEN PRINT USING "16X,""Using no insert inside tube"""
1607  IF Inn=2 THEN PRINT USING "16X,""Using wire wrap insert inside tube"""
1608  IF Inn=3 THEN PRINT USING "16X,""Using HEATEX insert inside tube"""
1609  IF Istu=0 THEN
1610  IF Inn=1 THEN PRINT USING "16X,""Using twisted tape insert inside tube"""
1612  ELSE
1613  IF Inn=1 THEN PRINT USING "16X,""Using wire wrap insert inside tube"""
1616  END IF
1617  IF Iic=0 AND Ife=1 THEN Ac=26.4
1618  IF Iic=1 THEN Ac=0.
1619  BEEP
1620  IF Ijob=1 THEN 1648
1621  PRINTER IS 1
1622! INPUT "NAME FOR A TEMPORARY PLOT FILE (TO BE PURGED)",P_file$
1623  P_file$="DUMMY"
1624  BEEP
1634  CREATE BDAT P_file$,10
1644  ASSIGN @Filep TO P_file$
1648  IF Ijob=1 THEN
1651  Iov=1
1654  GOTO 1689
1657  END IF
1660  BEEP
1661  INPUT "SELECT OUTPUT (0=SHORT, 1=LONG)",Iov
1666  Iov=Iov+1
1667  PRINTER IS 701
1672  IF Ityp=0 THEN PRINT USING "16X,""Tube Enhancement    : SMOOTH TUBE"""
1673  IF Ityp=1 THEN PRINT USING "16X,""Tube Enhancement    : FINNED TUBE"""
```

```
1674  IF Ityp=2 THEN PRINT USING "16X,""Tube Enhancement    : WIRE-WRAPPED SMOOT
 TUBE"""
1675  IF Ityp=3 THEN PRINT USING "16X,""Tube Enhancement    : LPD KORODENSE TUBE
""
1678  IF Ityp=4 THEN PRINT USING "16X,""Tube Enhancement    : WIRE-WRAPPED LPD K
RODENSE TUBE"""
1679  BEEP
1681  IF Imc=0 THEN PRINT USING "16X,""Tube material       : COPPER"""
1682  IF Imc=1 THEN PRINT USING "16X,""Tube material       : STAINLESS-STEEL"""
1683  IF Imc=2 THEN PRINT USING "16X,""Tube material       : ALUMINUM"""
1684  IF Imc=3 THEN PRINT USING "16X,""Tube material       : 90/10 CU/NI"""
1685  IF Imc=4 THEN PRINT USING "16X,""Tube material       : TITANIUM"""
1686  IF Ipc=0 THEN PRINT USING "16X,""Pressure condition : VACUUM"""
1687  IF Ipc=1 THEN PRINT USING "16X,""Pressure condition : ATMOSPHERIC"""
1688! PRINT USING "16X,""Fin pitch, width, and height (mm): "",DD.DD,2X,Z.DD,2X
Z.DD";Fp,Fw,Fh
1689  IF (Iwil=0 OR Iwil=2) AND Im=2 THEN
1690  Ijob=1
1693  Iwd=1
1696  CALL Wilson(Ci)
1699  END IF
1702  J=0
1712  IF Iov=1 THEN
1722  PRINT
1723  IF Ihi=1 THEN
1724  PRINT USING "10X,""Data  Vw      Uo          Ho         Qp        Tcf     Ts
   Rexp"""
1725  PRINT USING "10X,""  # (m/s)  (W/m^2-K)  (W/m^2-K)   (W/m^2)   (C)     (C)
 (S-R)"""
1726  ELSE
1728  PRINT USING "10X,""Data    Vw        Uo           Ho          Qp          T
f     Ts"""
1729  PRINT USING "10X,"" #    (m/s)   (W/m^2-K)    (W/m^2-K)   (W/m^2)         (
)     (C)"""
1730  END IF
1740  END IF
1747  Zx=0
1750  Zx2=0
1753  Zxy=0
1756  Zy=0
1759  Sx=0
1762  Sy=0
1765  Sxs=0
1768  Sxy=0
1771  Go_on=1
1774 Repeat:!
```

```
177  J=J+1
180  IF Im=1 THEN
83   BEEP
86   INPUT "LIKE TO CHECK NG CONCENTRATION (1=Y,0=N)?",Ng
89   IF J=1 THEN
92   OUTPUT 709;"AR AF40 AL41 VR5"
95   OUTPUT 709;"AS SA"
98   END IF
01   BEEP
04   INPUT "ENTER FLOWMETER READING",Fm
07   OUTPUT 709;"AR AF60 AL62 VR5"
10   OUTPUT 709;"AS SA"
13   ENTER 709;Etp
16   OUTPUT 709;"AS SA"
19   BEEP
22   INPUT "CONNECT VOLTAGE LINE",Ok
25   ENTER 709;Bvol
28   BEEP
831  INPUT "DISCONNECT VOLTAGE LINE",Ok
834  IF Bvol<.1 THEN
837  BEEP
840  BEEP
843  INPUT "INVALID VOLTAGE - TRY AGAIN!",Ok
846  GOTO 1819
849  END IF
858  OUTPUT 709;"AS SA"
861  ENTER 709;Bamp
862  Etp=Etp*1.E+6
863  OUTPUT 709;"AR AF40 AL47 VR5"
874  Nn=7
876  FOR I=0 TO Nn
879  OUTPUT 709;"AS SA"
885  Se=0
888  FOR K=1 TO 10
891  ENTER 709;E
894  Se=Se+E
897  NEXT K
900  Emf(I)=ABS(Se/10)
916  Emf(I)=Emf(I)*1.E+6
918  NEXT I
921  OUTPUT 709;"AS SA"
924  OUTPUT 713;"T1R2E"
927  WAIT 2
930  ENTER 713;T11
933  OUTPUT 713;"T2R2E"
936  WAIT 2
```

```
1939  ENTER 713;T2
1942  OUTPUT 713;"T1R2E"
1945  WAIT 2
1948  ENTER 713;T12
1951  T1=(T11+T12)*.5
1954  OUTPUT 713;"T3R2E"
1960  BEEP
1970  INPUT "ENTER PRESSURE GAGE READING (Pga)",Pga
1971  Pvap1=Pga*6894.7 ! PSI TO Pa
1972  OUTPUT 709;"AR AF64 AL64 VR5"
1973  OUTPUT 709;"AS SA"    ! PRESSURE TRANSDUCER
1974  Ss=0
1975  FOR K=1 TO 20
1976  ENTER 709;Etran
1977  Ss=Ss+Etran
1978  NEXT K
1979  Ptran=ABS(Ss/20)
1980  BEEP
1981! PRESSURE IN Pa FROM TRANSDUCER
1982  Pvap2=(-2.93604*Ptran+14.7827)*6894.7
1985  ELSE
1986  IF Istu=0 THEN
1989  ENTER @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
1990  ELSE
1992  ENTER @File;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1,
2,Phg,Pwater
1994  END IF
1996  IF J=1 OR J=20 OR J=Nrun THEN
1997  Ng=1
1998  ELSE
1999  Ng=0
2000  END IF
2002  END IF
2003  IF Istu=0 THEN
2008  Tsteam1=FNTvsv57(Emf(0))
2009  Tsteam1=Tsteam1-273.15
2010  Tsteam2=FNTvsv56(Emf(1))
2011  Tsteam2=Tsteam2-273.15
2012  Tsteam=Tsteam1
2015  Troom=FNTvsv58(Emf(2))
2023  Troom=Troom-273.15
2038  Tcon=FNTvsv58(Emf(7))
2039  Tcon=Tcon-273.15
2042  ELSE
2043  Tsteam=FNTvsv(Emf(0))
2044  Troom=FNTvsv(Emf(3))
```

```
045  Tcon=FNTvsv(Emf(4))
046  END IF
048  Psat=FNPvst(Tsteam)
050  Rohg=13529-122*(Troom-26.85)/50
053  Rowater=FNRhow(Troom)
063  IF Istu=0 THEN
081  Ptest1=Pvap1
082  Ptest2=Pvap2
083  ELSE
084  Ptest2=(Phg*Rohg-Pwater*Rowater)*9.81/1000
085  END IF
087  Pks=Psat*1.E-3
088  Pkp=Ptest2*1.E-3
089  Pkt=Pks
092  Tsat=FNTvsp(Psat)
098  Vst=FNVvst(Tsteam)
104  Ppng=(Ptest2-Psat)/Ptest2
121  Ppst=1-Ppng
122  Mwv=18.016
123  IF Ift=1 THEN Mwv=137   ! TO BE CORRECTED
124  IF Ift=2 THEN Mwv=62
125  Vfng=(Ptest2-Psat)/Ptest2
126  Mfng=1/(1+(1/Vfng-1)*Mwv/28.97)
127  Mfng=Mfng*100
128  Vfng=Vfng*100
131  BEEP
134  IF Iov=2 THEN
137  PRINT
138! RECORD TIME OF TAKING DATA
139  IF Im=1 THEN
140     OUTPUT 709;"TD"
141     ENTER 709;Told$
142  END IF
144  PRINT USING "10X,""Data set number             = "",DD,4X,14A";J,Told$
145  OUTPUT 709;"AR AF40 AL40 VR5"
146  OUTPUT 709;"AS SA"
149  END IF
152  IF Iov=2 AND Ng=1 THEN
155  PRINT USING "10X,""   Psat    Ptran   Tmeas    Tsat         NG %"""
158  PRINT USING "10X,""  (kPa)   (kPa)     (C)     (C)        Molal """
161  PRINT USING "11X,1(3D.DD,2X),1(3D.DD,3X),2(3D.DD,2X),2X,1(M3D.D,2X)";Pks,P
p,Tsteam,Tsat,Mfng
164  PRINT
167  END IF
170  IF Mfng>.5 THEN
173  BEEP
```

```
2176  IF Im=1 AND Ng=1 THEN
2179  BEEP
2182  PRINT
2185  PRINT USING "10X,""Energize the vacuum system """
2188  BEEP
2191  INPUT "OK TO ACCEPT THIS RUN (1=Y,0=N)?",Ok
2194  IF Ok=0 THEN
2197  BEEP
2200  DISP "NOTE: THIS DATA SET WILL BE DISCARDED!! "
2203  WAIT 5
2206  GOTO 1780
2209  END IF
2212  END IF
2215  END IF
2218  IF Im=1 THEN
2221  IF Fm<10 OR Fm>100 THEN
2224  Ifm=0
2227  BEEP
2230  INPUT "INCORRECT FM (1=ACCEPT,0=DELETE)",Ifm
2233  IF Ifm=0 THEN 1804
2236  END IF
2239  END IF
2242! ANALYSIS BEGINS
2243  IF Istu=0 THEN
2252  Ti1=FNTvsv58(Emf(3))
2262  Ti2=FNTvsv55(Emf(5))
2272  To1=FNTvsv58(Emf(4))
2282  To2=FNTvsv55(Emf(6))
2292  Ti1=Ti1-273.15
2302  Ti2=Ti2-273.15
2312  To1=To1-273.15
2322  To2=To2-273.15
2332  Tdel1=To1-Ti1
2342  Tdel2=To2-Ti2
2352  Tdel3=T2-T1
2353  Etp1=Emf(3)+Etp/20.
2354  Dtde=2.5931E-2-1.50464E-6*Etp1+1.21701E-10*Etp1^2-5.1164E-15*Etp1^3+3.22
E-19*Etp1^4
2355  Tris=Dtde*Etp/10.
2358  To3=Ti1+Tris
2359  IF Iov=2 THEN
2361  PRINT USING "1X,""  TIN1    TOUT1    TIN3     TOUT3    DELT1    DELT3    TPILE
"""
2362  PRINT USING "1X,""   (TEFLON)         (QUARTZ) """
2364  PRINT USING "2X,7(3D.DD,2X)";Ti1,To1,T1,T2,Tdel1,Tdel3,Tris
2365  END IF
```

```
367  Er1=ABS(Ti1-T1)
368  Er3=ABS(Ti2-T1)
369  PRINTER IS 1
370  BEEP
375  Er2=ABS((T2-T1)-(Tris))/(T2-T1)
377  IF Er2>.05 AND Im=1 THEN
378  BEEP
379  PRINT "QCT AND T-PILE DIFFER BY MORE THAN 5%"
380  Ok2=1
381  IF Ok2=0 AND Er2>.05 AND Im=1 THEN 1780
382  END IF
383  PRINTER IS 701
384  ELSE
385  Ti=FNTvsv(Emf(2))
386  Grad=FNGrad((T1+T2)*.5)
387  To=Ti+ABS(Etp)/(10*Grad)*1.E+6
388  Ti1=Ti
389  To3=To
391  END IF
392  IF Istu=0 AND Itm=0 THEN
393  T1i=Ti1
394  T2o=To1
395  END IF
396  IF Itm=1 THEN
397  T1i=T1
398  T2o=T2
399  END IF
400  IF Itm=2 THEN
401  T1i=Ti1
402  T2o=To3
403  END IF
404  Tavg=(T1i+T2o)*.5
405  Ift=0
406  Cpw=FNCpw(Tavg)
407  Rhow=FNRhow(Tavg)
408  IF Istu=0 THEN
410  Md=(6.7409*Fm+13.027)/1000.
411  Md=Md*(1.0365-1.96644E-3*T1i+5.252E-6*T1i^2)/1.0037
412  ELSE
413  Md=1.04805E-2+6.80932E-3*Fm
414  Md=Md*(1.0365-1.96644E-3*T1i+5.252E-6*T1i^2)/.995434
415  END IF
417  Mf=Md/Rhow
418  Vw=Mf/(PI*Di^2/4)
419  Vws=Vw*(Di/1.27E-2)^2
421  IF Istu=0 AND Iwth=0 THEN !SWENSEN FRIC. SMOOTH COPPER TUBE
```

```
2422  IF Inn=0 AND Vw<.5 THEN T2o=T2o-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.98E-
Vw^3)
2423  IF Inn=1 THEN T2o=T2o-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3)
2424  IF Inn=2 THEN T2o=T2o-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3)
2425  IF Inn=3 THEN T2o=T2o-(8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
2426  END IF
2428  IF Istu=0 AND Iwth=2 THEN !FRIC FACTOR SMTH TITANIUM TUBE
2429  IF Inn=0 AND Vw<.5 THEN T2o=T2o-(-4.62E-5-7.53E-4*Vw+1.80E-3*Vw^2-8.84E-
Vw^3)
2430  IF Inn=3 THEN T2o=T2o-(2.09E-4+9.74E-4*Vw+2.12E-3*Vw^2-3.31E-5*Vw^3)
2431  END IF
2433  IF Istu=0 AND Iwth=1 THEN !FRICTION FACTORS FOR KORODENSE
2434  IF Inn=0 AND Vw>.5 THEN T2o=T2o-(-3.386E-4+1.88E-3*Vw+6.013E-4*Vw^2+4.13
-5*Vw^3)
2435  IF Inn=3 THEN T2o=T2o-(2.089E-4+9.202E-4*Vw+1.893E-3*Vw^2-2.781E-5*Vw^3)
2436  END IF
2437  IF Istu=1 THEN
2439  IF Inn=0 THEN T2o=T2o-(.0138+.001*Vw^2)
2440  IF Inn=1 THEN T2o=T2o-.004*Vws^2
2441  IF Inn=2 THEN T2o=T2o-.004*Vws^2
2444  END IF
2445  Q=Md*Cpw*(T2o-T1i)
2446  Qp=Q/(PI*Do*L)
2447  Ift=0
2448  Kw=FNKw(Tavg)
2449  Muw=FNMuw(Tavg)
2450  Rei=Rhow*Vw*Di/Muw   ! ASSUMED SAME FOR KORODENSE
2451  Prw=FNPrw(Tavg)
2452  Fe1=0.
2453  Fe2=0.
2454  Cf=1.
2455  Prwf=Prw
2456  Reif=Rei
2461  IF Ihi=0 THEN
2463  Ome=Rei^Rexp*Prw^.3333*Cf
2465  END IF
2466  IF Ihi=1 THEN
2467  Sra=.88-(.24/(4.+Prwf))
2468  Srb=.333333+.5*EXP(-.6*Prwf)
2470  Ome=(5.+.015*Reif^Sra*Prwf^Srb)
2471  END IF
2472  IF Ihi=2 THEN
2473  Epsi=(1.82*LGT(Rei)-1.64)^(-2)
2474  Ppl1=1.+3.4*Epsi
2475  Ppl2=11.7+1.8*Prw^(-1/3)
2476  Pp1=(Epsi/8)*Rei*Prw
```

```
2477 Pp2=(Ppk1+Ppk2*(Epsi/8)^.5*(Prw^.6666-1))
2478 Ome=Pp1/Pp2
2479 END IF
2481 Hi=Kw/Di*Ci*Ome
2482 IF Ife=0 THEN GOTO 2491
2483 P1=PI*(Do+Di)
2484 A1=(D1-Di)*PI*(D1+Di)*.5
2485 M1=(Hi*P1/(Kcu*A1))^.5
2486 P2=PI*(Di+D2)
2487 A2=(D2-Di)*PI*(Di+D2)*.5
2488 M2=(Hi*P2/(Kcu*A2))^.5
2489 Fe1=FNTanh(M1*L1)/(M1*L1)
2490 Fe2=FNTanh(M2*L2)/(M2*L2)
2491 Dt=Q/(PI*Di*(L+L1*Fe1+L2*Fe2)*Hi)
2492 IF Ihi=0 THEN
2494 Cfc=(Muw/FNMuw(Tavg+Dt))^.14
2495 IF ABS((Cfc-Cf)/Cfc)>.001 THEN
2497 Cf=(Cf+Cfc)*.5
2500 GOTO 2461
2501 END IF
2503 END IF
2504 IF Ihi=1 THEN
2505 Prwfc=FNPrw(Tavg+Dt)
2506 Reifc=Vw*Di*FNRhow(Tavg+Dt)/FNMuw(Tavg+Dt)
2507 IF ABS((Prwfc-Prwf)/Prwfc)>.001 OR ABS((Reifc-Reif)/Reifc)>.001 THEN
2508 Prwf=(Prwfc+Prwf)/2.
2509 Reif=(Reifc+Reif)/2.
2510 GOTO 2461
2511 END IF
2513 END IF
2516 Ift=Ifto
2517 Lmtd=(T2o-T1i)/LOG((Tsteam-T1i)/(Tsteam-T2o))
2518 Uo=Q/(Lmtd*PI*Do*L)
2519 Ho=1/(1/Uo-Do*L/(Di*(L+L1*Fe1+L2*Fe2)*Hi)-Rm)
2520 Tcf=Qp/Ho
2521 Cpsc=FNCpw((Tcon+Tsteam)*.5)
2522 Hfg=FNHfg(Tsteam)
2524 Two=Tsteam-Qp/Ho
2527 Tfilm=Tsteam/3+Two*2/3
2530 Kf=FNKw(Tfilm)
2533 Rhof=FNRhow(Tfilm)
2536 Muf=FNMuw(Tfilm)
2539 Hpq=.651*Kf*(Rhof^2*9.81*Hfg/(Muf*Do*Qp))^.3333
2541 Hnuss=.728*(Kf^3*9.81*Hfg*Rhof^2/(Muf*Do*Tcf))^.25
2542 Alp1=.728*Ho/Hnuss
2548 Tfm(J-1)=Tfilm
2551 Qpa(J-1)=Qp
```

```
2554  Y=Hpq*Qp^.3333
2557  X=Qp
2560  Sx=Sx+X
2563  Sy=Sy+Y
2566  Sxs=Sxs+X^2
2569  Sxy=Sxy+X*Y
2572  Q1=500
2575  Qloss=Q1/(100-25)*(Tsteam-Troom)  ! TO BE MODIFIED
2578  Hfc=FNHf(Tcon)
2584  Mdv=0
2587  Bp=(Bvol*100)^2/5.76
2590  Hsc=Cpsc*(Tsteam-Tcon)
2593  Mdvc=((Bp-Qloss)-Mdv*Hsc)/Hfg
2596  IF ABS((Mdv-Mdvc)/Mdvc)>.01 THEN
2599  Mdv=(Mdv+Mdvc)*.5
2602  GOTO 2593
2605  END IF
2608  Mdv=(Mdv+Mdvc)*.5
2611  Vg=FNVvst(Tsteam)
2614  Vv=Mdv*Vg/Ax
2620  F=(9.81*Do*Muf*Hfg)/(Vv^2*Kf*(Tsteam-Two))
2623  Nu=Ho*Do/Kf
2626  Ret=Vv*Rhof*Do/Muf
2629  Nr=Nu/Ret^.5
2630  Hfuj=.96*(9.81*Hfg/Tcf)^.2*Kf^.8*Vv^.1*Rhof^.5/(Do*Muf)^.3
2635  IF Iov=2 THEN
2645  PRINT
2647  PRINT USING "5X,"" Vw       Rei            Hi            Uo            Hfuj(DT)
   Hnu(Q)"""
2650  PRINT USING "5X,Z.DD,1X,3(MZ.3DE,1X),3X,2(MZ.3DE,3X)";Vw,Rei,Hi,Uo,Hfuj,
q
2651  PRINT
2653  PRINT USING "5x,"" Vv         Ho            q             Tcf        NuRe        F
   Hnu(DT)"""
2655  PRINT USING "5X,Z.DD,1X,2(MZ.3DE,1X),2X,3D.DD,2X,3(MZ.3DE,1X)";Vv,Ho,Qp,
f,Nr,F,Hnuss
2656  PRINT
2658  END IF
2659  IF Iov=1 THEN
2660  IF Ihi=1 THEN
2661  PRINT USING "11X,DD,2X,Z.DD,1X,3(MD.3DE,1X),2(3D.DD,1X),D.DDD";J,Vw,Uo,H
Qp,Tcf,Tsteam,Sra
2662  ELSE
2668  PRINT USING "11X,DD,4X,Z.DD,2X,2(MD.3DE,2X),Z.3DE,3X,3D.DD,2X,3D.DD";J,V
Uo,Ho,Qp,Tcf,Tsteam
2671  END IF
```

```
674  END IF
675  IF Im=2 THEN
684  IF (Iwil=0 AND Ijob=1) OR Iwil<>0 THEN OUTPUT @Filep;Qp,Ho
694  END IF
707  BEEP
708  IF Im=1 THEN
709  IF (Iwil=0 AND Ijob=1) OR Iwil=1 THEN OUTPUT @Filep;Qp,Ho
711  INPUT "CHANGE TCOOL RISE? 1=Y, 2=N",Itr
712  IF Itr=1 THEN GOTO 2384
713  INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Oks
714  IF Oks=1 THEN
725  OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
735  Alp2=Alp1+Alp2
749  ELSE
752  J=J-1
755  END IF
758  BEEP
761  INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
764  Nrun=J
767  IF Go_on<>0 THEN Repeat
770  ELSE
773  IF J<Nrun THEN Repeat
776  END IF
779  IF Ijob=1 THEN 2809
782  IF Iwil=0 THEN
785  ASSIGN @File TO *
788  Ijob=1
791  Iwd=1
794! CALL Wilson(Ci)
797  Im=2
800  ASSIGN @File TO D_file$
803  GOTO 1136
806  END IF
809  IF Ifg=0 THEN
812  PRINT
815  S1=(Nrun*Sxy-Sy*Sx)/(Nrun*Sxs-Sx^2)
818  Ac=(Sy-S1*Sx)/Nrun
822  PRINT USING "10X,""Least-Squares Line for Ho vs q curve:"""
824  PRINT USING "10X,""  Slope       = "",MD.4DE";S1
827  PRINT USING "10X,""  Intercept   = "",MD.4DE";Ac
830  END IF
833  BEEP
843! INPUT "ENTER SAME TEMPORARY PLOT FILE NAME",Fplot$
853  ASSIGN @Filep TO P_file$
863  FOR I=1 TO Nrun
873  ENTER @Filep;Qp,Ho
```

```
2873  ENTER @Filep;Qp,Ho
2883  Xc=LOG(Qp/Ho)
2884  Yc=LOG(Qp)
2885  Zx=Zx+Xc
2886  Zx2=Zx2+Xc^2
2887  Zxy=Zxy+Xc*Yc
2888  Zy=Zy+Yc
2889  NEXT I
2890  Bb=.75
2891  Aa=EXP((Zy-Bb*Zx)/Nrun)
2892  PRINT
2893  PRINT USING "10X,""Least-squares line for q = a*delta-T^b"""
2894  PRINT USING "12X,""a = "",MZ.4DE";Aa
2895  PRINT USING "12X,""b = "",MZ.4DE";Bb
2896  IF Ift=0 THEN
2897  IF Ipc=0 THEN
2898  Qps=2.5E+5
2899  IF Iic=0 THEN Hop=9326
2902  IF Iic=1 THEN Hop=10165*(.01905/Do)^.33333
2905  END IF
2908  IF Ipc=1 THEN
2911  Qps=7.5E+5
2914  IF Iic=0 THEN Hop=7176
2917  IF Iic=1 THEN Hop=7569*(.01905/Do)^.33333
2920  END IF
2923  Hos=Aa^(1/Bb)*Qps^((Bb-1)/Bb)
2926  IF Ipc=0 THEN Aas=2.32E+4
2929  IF Ipc=1 THEN Aas=2.59E+4
2930  Alpsm=.876   !SWENSEN DATA
2931  IF Iwil=0 THEN GOTO 2959
2933  Enrat=Alp2/Alpsm
2934  Enr=Hos/Hop
2935! Enr=Aa/Aas
2938  PRINT
2941! PRINT USING "10X,""Values computed at q = "",Z.DD,"" (MW/m^2):""";Qps/1.E
6
2944! PRINT USING "12X,""Heat-transfer coefficient = "",DDD.DDD,"" (kW/m^2.K)""
;Hos/1000
2947  PRINT USING "12x,""Enhancement ratio (Del-T) =  "",2D.3D";Enrat
2950! PRINT USING "10X,""Enhancement ratio at constant Delta-T  = "",DD.DD";Enr
2953! PRINT USING "10X,""Enhancement ratio at constant q        = "",DD.DD";Enr
1.3333
2956  ELSE
2959  PRINT
2962  IF Ift=1 THEN
2965  Aas=2687.2  ! ZEBROWSKI (V = 0.4 m/s)
2968  Aas=2557.0*(.01905/Do)^.33333  ! VAN PETTEN (V = 0.25 m/s)
```

```
368  Aas=2557.0*(.01905/Do)^.33333  ! VAN PETTEN (V = 0.25 m/s)
371  END IF
374  IF Ift=2 THEN Aas=9269.7*(.01905/Do)^.33333
377  Edt=Aa/Aas
380  Eq=Edt^(4/3)
383! PRINT USING "10X,""Enhancement (q)      = "",DD.3D";Eq
386! PRINT USING "10X,""Enhancement (Del-T) = "",DD.3D";Edt
389  END IF
392! IF Im=1 THEN
395  BEEP
398  PRINT
001  PRINT USING "10X,""NOTE: "",ZZ,"" data points were stored in file "",10A";
,D_file$
004! END IF
007  BEEP
013  PRINT
016  PRINT USING "10X,""NOTE: "",ZZ,"" X-Y pairs were stored in data file "",10
";J,Plot$
031  BEEP
073  ASSIGN @File TO *
079  ASSIGN @Filep TO *
080  PURGE "DUMMY"
094  IF Iso=2 THEN CALL Raw
100  IF Iso=3 THEN CALL Wilson(Ci)
103  IF Iso=4 THEN CALL Modify
106  IF Iso=5 THEN CALL Purg
112  IF Iso=6 THEN CALL Renam
116  END
118  DEF FNPvst(Tc)
121  COM /Fld/ Ift,Istu
124  DIM K(8)
127  IF Ift=0 THEN
130  DATA -7.691234564,-26.08023696,-168.1706546,64.23285504,-118.9646225
133  DATA 4.16711732,20.9750676,1.E9,6
136  READ K(*)
139  T=(Tc+273.15)/647.3
142  Sum=0
145  FOR N=0 TO 4
148  Sum=Sum+K(N)*(1-T)^(N+1)
151  NEXT N
154  Br=Sum/(T*(1+K(5)*(1-T)+K(6)*(1-T)^2))-(1-T)/(K(7)*(1-T)^2+K(8))
157  Pr=EXP(Br)
160  P=22120000*Pr
163  END IF
166  IF Ift=1 THEN
169  Tf=Tc*1.8+32+459.6
172  P=10^(33.0655-4330.98/Tf-9.2635*LGT(Tf)+2.0539E-3*Tf)
```

```
3175  P=P*101325/14.696
3178  END IF
3181  IF Ift=2 THEN
3184  A=9.394685-3066.1/(Tc+273.15)
3187  P=133.32*10^A
3190  END IF
3193  RETURN P
3196  FNEND
3199  DEF FNHfg(T)
3202  COM /Fld/ Ift,Istu
3205  IF Ift=0 THEN
3208  Hfg=2477200-2450*(T-10)
3211  END IF
3214  IF Ift=1 THEN
3217  Tf=T*1.8+32
3220  Hfg=7.0557857E+1-Tf*(4.838052E-2+1.2619048E-4*Tf)
3223  Hfg=Hfg*2326
3226  END IF
3229  IF Ift=2 THEN
3232  Tk=T+273.15
3235  Hfg=1.35264E+6-Tk*(6.38263E+2+Tk*.747462)
3238  END IF
3241  RETURN Hfg
3244  FNEND
3247  DEF FNMuw(T)
3250  COM /Fld/ Ift,Istu
3253  IF Ift=0 THEN
3256  A=247.8/(T+133.15)
3259  Mu=2.4E-5*10^A
3262  END IF
3265  IF Ift=1 THEN
3268  Mu=8.9629819E-4-T*(1.1094609E-5-T*5.566829E-8)
3271  END IF
3274  IF Ift=2 THEN
3277  Tk=1/(T+273.15)
3280  Mu=EXP(-11.0179+Tk*(1.744E+3-Tk*(2.80335E+5-Tk*1.12661E+8)))
3283  END IF
3286  RETURN Mu
3289  FNEND
3292  DEF FNVvst(Tt)
3295  COM /Fld/ Ift,Istu
3298  IF Ift=0 THEN
3301  P=FNPvst(Tt)
3304  T=Tt+273.15
3307  X=1500/T
3310  F1=1/(1+T*1.E-4)
```

```
313  F2=(1-EXP(-X))^2.5*EXP(X)/X^.5
316  B=.0015*F1-.000942*F2-.0004882*X
319  K=2*P/(461.52*T)
322  V=(1+(1+2*B*K)^.5)/K
325  END IF
328  IF Ift=1 THEN
331  Tf=Tt*1.8+32
334  V=13.955357-Tf*(.16127262-Tf*5.1726190E-4)
337  V=V/16.018
340  END IF
343  IF Ift=2 THEN
346  Tk=Tt+273.15
349  P=FNPvst(Tt)
352  V=133.95*Tk/P
355  END IF
358  RETURN V
361  FNEND
364  DEF FNCpw(T)
367  COM /Fld/ Ift,Istu
370  IF Ift=0 THEN
373  Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
376  END IF
379  IF Ift=1 THEN
382  Cpw=9.2507273E-1+T*(9.3400433E-4+1.7207792E-6*T)
385  END IF
388  IF Ift=2 THEN
391  Tk=T+273.15
394  Cpw=4.1868*(1.6884E-2+Tk*(3.35083E-3-Tk*(7.224E-6-Tk*7.61748E-9)))
397  END IF
400  RETURN Cpw*1000
403  FNEND
406  DEF FNRhow(T)
409  COM /Fld/ Ift,Istu
412  IF Ift=0 THEN
415  Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
418  END IF
421  IF Ift=1 THEN
424  Ro=1.6207479E+3-T*(2.2186346+T*2.3578291E-3)
427  END IF
430  IF Ift=2 THEN
433  Tk=T+273.15-338.15
436  Vf=9.24848E-4+Tk*(6.2796E-7+Tk*(9.2444E-10+Tk*3.057E-12))
439  Ro=1/Vf
442  END IF
445  RETURN Ro
448  FNEND
```

```
3451  DEF FNPrw(T)
3454  Prw=FNCpw(T)*FNMuw(T)/FNKw(T)
3457  RETURN Prw
3460  FNEND
3463  DEF FNKw(T)
3466  COM /Fld/ Ift,Istu
3469  IF Ift=0 THEN
3472  X=(T+273.15)/273.15
3475  Kw=-.92247+X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
3478  END IF
3481  IF Ift=1 THEN
3484  Kw=8.2095238E-2-T*(2.2214286E-4+T*2.3809524E-8)
3487  END IF
3490  IF Ift=2 THEN
3493  Tk=T+273.15
3496  Kw=4.1868E-4*(519.442+.320920*Tk)
3499  END IF
3502  RETURN Kw
3505  FNEND
3508  DEF FNTanh(X)
3511  P=EXP(X)
3514  Q=EXP(-X)
3517  Tanh=(P-Q)/(P+Q)
3520  RETURN Tanh
3523  FNEND
3526  DEF FNTvsv(V)
3529  COM /Cc/ C(7)
3532  T=C(0)
3535  FOR I=1 TO 7
3538  T=T+C(I)*V^I
3541  NEXT I
3544! T=T+4.73386E-3+T*(7.692834E-3-T*8.077927E-5)
3547  RETURN T
3550  FNEND
3553  DEF FNHf(T)
3556  COM /Fld/ Ift,Istu
3559  IF Ift=0 THEN
3562  Hf=T*(4.203849-T*(5.88132E-4-T*4.5516031 7E-6))
3565  END IF
3568  IF Ift=1 THEN
3571  Tf=T*1.8+32
3574  Hf=8.2078571+Tf*(.19467857+Tf*1.3214286E-4)
3577  Hf=Hf*2.326
3580  END IF
3583  IF Ift=2 THEN
3586  Hf=250   ! TO BE VERIFIED
```

```
589  END IF
592  RETURN Hf*1000
595  FNEND
598  DEF FNGrad(T)
601  Grad=37.9853+.104388*T
604  RETURN Grad
607  FNEND
610  DEF FNTvsp(P)
613  Tu=190
616  Tl=10
619  Ta=(Tu+Tl)*.5
622  Pc=FNPvst(Ta)
625  IF ABS((P-Pc)/P)>.0001 THEN
628  IF Pc<P THEN Tl=Ta
631  IF Pc>P THEN Tu=Ta
634  GOTO 3619
637  END IF
640  RETURN Ta
643  FNEND
646  DEF FNSigma(T)
649  X=647.3-T-273.15
652  S=.1160936807/(1+.83*X)+1.121404688E-3-5.75280518E-6*X+1.28627465E-8*X^2-1
14971929E-11*X^3
655  RETURN S*.001*X^2
658  FNEND
661  SUB Raw
662  COM /Fld/ Ift,Istu
664  DIM X(28)
670  INPUT "ENTER TUBE NUMBER",Itn
676  INPUT "ENTER FILE NAME",File$
679  ASSIGN @File TO File$
680  INPUT "STUDENT (0=Swensen)",Istu
681  INPUT "SMOOTH OR FINNED (0=SMOOTH, 1=FINNED)",Ifg
683  INPUT "ENTER TUBE SIZE (0=S,1=M,2=L,3=OMC)",Itds
685  INPUT "ENTER PRESSURE CONDITION (0=V,1=A)",Ipc
688  IF Ipc=0 AND Ift=0 THEN Vs=2
691  IF Ipc=0 AND Ift=2 THEN Vs=10
692  IF Ipc=1 AND Ift=0 THEN Vs=1
693  IF Ipc=1 AND Ift=1 THEN Vs=.25
694  IF Istu=1 THEN Vs=2
696  Nrun=18
700  INPUT "ENTER NUMBER OF RUNS",Nrun
703  PRINTER IS 701
706  PRINT
709  PRINT
710  IF Istu=0 THEN PRINT USING "10X,""Data of Swensen"""
```

```
6715  IF Ift=0 THEN PRINT USING "10X,""Vapor is steam"""
6716  IF Ift=1 THEN PRINT USING "10X,""Vapor is R-113"""
6717  IF Ift=2 THEN PRINT USING "10X,""Vapor is ethylene glycol"""
6719  IF Itds=0 THEN PRINT USING "10X,""Tube diameter:   Small"""
6720  IF Itds=1 THEN PRINT USING "10X,""Tube diameter:   Medium"""
6721  IF Itds=2 THEN PRINT USING "10X,""Tube diameter:   Large"""
6722  IF Itds=3 THEN PRINT USING "10X,""Tube diameter:   OMC"""
6724  PRINT
6725  PRINT USING "10X,""Tube Number:         "",ZZ";Itn
6726  PRINT USING "10X,""File Name:           "",14A";File$
6727  IF Ifg=0 THEN PRINT USING "10X,""Tube Type:   Smooth"""
6728  IF Ifg=1 THEN PRINT USING "10X,""Tube Type:   Finned"""
6730  IF Ipc=0 THEN
6731  PRINT USING "10X,""Pressure Condition: Vacuum"""
6732  ELSE
6733  PRINT USING "10X,""Pressure Condition: Atmospheric"""
6734  END IF
6735! PRINT USING "10X,""Vapor Velocity:      "",DD.DD,"" (m/s)""";Vs
6736  ENTER @File;Ifg,Inn
6739  IF Itds=1 OR Itds=2 THEN Di=.0127
6742  IF Itds=0 OR Itds=3 THEN Di=.009525
6747  ENTER @File;Iwt,Fp,Fw,Fh
6748  IF Istu=0 AND Ifg=1 THEN
6750  Fp=Fp-1
6751  PRINT USING "10X,""Fin spacing, width and height (mm): "",DD.DD,2X,Z.DD,2
,Z.DD";Fp,Fw,Fh
6752  END IF
6756  PRINT
6757  PRINT USING "10X,""Data    Vw     Tin    Tout      Ts"""
6758  PRINT USING "10X,"" #    (m/s)    (C)     (C)     (C)"""
6760  PRINT
6763  FOR I=1 TO Nrun
6766  ENTER @File;X(*)
6769  Ts=FNTvsv57((X(8)+X(9))/2.)
6770  Ts=Ts-273.15
6772  Fm=X(3)
6775  T1=X(4)
6778  T2=X(5)
6781  Tavg=(T1+T2)*.5
6784  Ift=0
6785  Rhow=FNRhow(Tavg)
6787  Md=(6.7409*Fm+13.027)/1000.
6790  Md=Md*(1.0365-1.96644E-3*T1+5.252E-6*T1^2)/1.0037
6793  Mf=Md/Rhow
6796  Vw=Mf/(PI*Di^2/4)
6799  IF Inn=0 AND Vw .5 THEN T2=T2-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.96E-5*
^3)
```

```
809  IF Inn=1 THEN T2=T2-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3)
810  IF Inn=2 THEN T2=T2-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3)
811  IF Inn=3 THEN T2=T2-(8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
814  PRINT USING "10X,DD,5X,D.DD,3X,2(DD.DD,3X),DDD.DD";I,Vw,T1,T2,Ts
817  NEXT I
820  ASSIGN @File TO *
823  SUBEND
826  SUB Wilson(Ci)
829  COM /Wil/ Nrun,Itm,Iwth,Imc,Ife,Ijob,Iwd,Ifg,Ipco,Ifto,Iwil,Ihi,Ioc,Inam,K
u,Rexp,Rm
832  COM /Fld/ Ift,Istu
833  COM /Geom/ D1,D2,Di,Do,L,L1,L2
835  DIM Emf(20),Bvo(25),Bam(25),Eata(25),Ear(25,7),Fma(25),T1a(25),T2a(25)
845  IF Ioc=0 THEN
847  PRINT USING "16X,""Nusselt theory is used for Ho"""
848  ELSE
849  PRINT USING "16X,""Fujii correlation used for Ho"""
850  END IF
853  BEEP
856  INPUT "RE-ENTER DATA FILE BEING PROCESSED",D_file$
859  BEEP
862  INPUT "GIVE A NAME FOR XY PLOT-DATA FILE",Plot$
865  CREATE BDAT Plot$,10
868  ASSIGN @Io_path TO Plot$
871  Jj=0
874  ASSIGN @File TO D_file$
877  ENTER @File;Ifg,Inn
878  IF Istu=0 THEN
883  ENTER @File;Ddd,Ddd,Ddd,Ddd
884  ELSE
885  IF Ifg=0 THEN ENTER @File;Iwt
886  IF Ifg=1 THEN ENTER @File;Fp,Fw,Fh
887  END IF
888  IF Jj=0 THEN
895  IF Ihi=0 THEN Ci=.027
896  IF Ihi=1 THEN Ci=1.00
897  IF Ihi=2 THEN Ci=1.00
899  IF Ifg=0 THEN Alp=1.2
900  IF Ifg=1 THEN Alp=2.6
901  IF Ift=2 AND Ifg=1 THEN Alp=5.0
904  END IF
907  J=0
910  Sx=0
913  Sy=0
916  Sxs=0
919  Sxy=0
```

```
6922! READ DATA FROM A USER-SPECIFIED FILE IF INPUT MODE (Im) = 2
6925  IF Jj=0 THEN
6926  IF Istu=0 THEN
6931  ENTER @File;Bvol,Bamp,Etp,Fm,T1,T2,Ddd,Ddd,Emf(*)
6932  ELSE
6934  ENTER @File;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1
2,Phg,Pwater
6936  END IF
6938  Bvo(J)=Bvol
6939  Bam(J)=Bamp
6940  Eata(J)=Etp
6943  Ear(J,0)=Emf(0)
6946  Ear(J,1)=Emf(1)
6949  Ear(J,2)=Emf(2)
6952  Ear(J,3)=Emf(3)
6955  Ear(J,4)=Emf(4)
6956  IF Istu=1 THEN GOTO 6961
6958  Ear(J,5)=Emf(5)
6959  Ear(J,6)=Emf(6)
6960  Ear(J,7)=Emf(7)
6961  Fma(J)=Fm
6962  T1a(J)=T1
6964  T2a(J)=T2
6967  ELSE
6970  Bvol=Bvo(J)
6973  Bamm=Bam(J)
6976  Etp=Eata(J)
6979  Emf(0)=Ear(J,0)
6982  Emf(1)=Ear(J,1)
6985  Emf(2)=Ear(J,2)
6988  Emf(3)=Ear(J,3)
6991  Emf(4)=Ear(J,4)
6992  IF Istu=1 THEN GOTO 6997
6994  Emf(5)=Ear(J,5)
6995  Emf(6)=Ear(J,6)
6996  Emf(7)=Ear(J,7)
6997  Fm=Fma(J)
6998  T1=T1a(J)
7000  T2=T2a(J)
7003  END IF
7004  IF Istu=0 THEN
7006  Tsat=FNTvsv57((Emf(0)+Emf(1))/2.)
7007  Tsat=Tsat-273.15
7009  Ti=FNTvsv58(Emf(3))
7010  To1=FNTvsv58(Emf(4))
7012  Ti=Ti-273.15
```

```
)13  To1=To1-273.15
)15  Etp1=Emf(3)+Etp/20.
)16  Dtde=2.5931E-2-1.50464E-6*Etp1+1.21701E-10*Etp1^2-5.1164E-15*Etp1^3+3.220
-19*Etp1^4
)17  Tris=Dtde*Etp/10.
)18  To=Ti+Tris
)19  ELSE
)20  Tsat=FNTvsv(Emf(0))
)21  Ti=FNTvsv(Emf(2))
)22  Grad=FNGrad((T1+T2)*.5)
)23  To=Ti+ABS(Etp)/(10*Grad)*1.E+6
)24  END IF
)25! CALCULATE THE LOG-MEAN-TEMPERATURE DIFFERENCE
)26  IF Istu=0 AND Itm=0 THEN
)27  Tf=Ti
028  Tl=To1
029  END IF
030  IF Itm=1 THEN
031  Tf=T1
032  Tl=T2
033  END IF
034  IF Itm=2 THEN
035  Tf=Ti
036  Tl=To
038  END IF
039  Tavg=(Tf+Tl)*.5
040  Trise=Tl-Tf
041  Lmtd=Trise/LOG((Tsat-Tf)/(Tsat-Tl))
042  Ift=0
043  Cpw=FNCpw(Tavg)
044  Rhow=FNRhow(Tavg)
045  Kw=FNKw(Tavg)
048  Muwa=FNMuw(Tavg)
051  Prw=FNPrw(Tavg)
054  Ift=Ifto
055  IF Istu=0 THEN
057  Mdt=(6.7409*Fm+13.027)/1000.
060  Md=Mdt*(1.0365-Tf*(1.96644E-3-Tf*5.252E-6))/1.0037
061  ELSE
062  Mdt=1.04805E-2+6.80932E-3*Fm
063  Md=Mdt*(1.0365-Tf*(1.96644E-3-Tf*5.252E-6))/.995434
065  END IF
066  Vf=Md/Rhow
067  Vw=Vf/(PI*Di^2/4)
068  Vws=Vw*(Di/1.27E-2)^2
070  IF Istu=0 AND Iwth=0 THEN !SWENSEN FRICTION FAC. FOR COPPER TUBE
```

```
7075  IF Inn=0 AND Vw>.5 THEN Trise=Trise-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.9
E-5*Vw^3)
7078  IF Inn=1 THEN Trise=Trise-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3
7079  IF Inn=2 THEN Trise=Trise-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3
7080  IF Inn=3 THEN Trise=Trise-(8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
7081  END IF
7083  IF Istu=0 AND Iwth=2 THEN !OKEEFE FRIC. FAC. FOR SMOOTH TITANIUM TUBE.
7085  IF Inn=0 AND Vw>.5 THEN Trise=Trise-(-4.62E-5-7.53E-4*Vw+1.80E-3*Vw^2-6.8
E-5*Vw^3)
7086  IF Inn=3 THEN Trise=Trise-(2.09E-4+9.74E-4*Vw+2.12E-3*Vw^2-3.31E-5*Vw^3)
7087  END IF
7088  IF Istu=0 AND Iwth=1 THEN !FRICTION FACTORS FOR KORODENSE
7089  IF Inn=0 AND Vw>.5 THEN Trise=Trise-(-3.386E-4+1.88E-3*Vw+6.013E-4*Vw^2+4
133E-5*Vw^3)
7090  IF Inn=3 THEN Trise=Trise-(2.089E-4+9.202E-4*Vw+1.893E-3*Vw^2-2.781E-5*Vw
3)
7091  END IF
7092  IF Istu=1 THEN
7093  IF Inn=0 THEN Trise=Trise-(.0138+.001*Vw^2)
7094  IF Inn=1 THEN Trise=Trise-.004*Vws^2
7095  IF Inn=2 THEN Trise=Trise-.004*Vws^2
7100  END IF
7108  Q=Md*Cpw*Trise
7111  Qp=Q/(PI*Do*L)
7114  Uo=Qp/Lmtd
7117  Re=Rhow*Vw*Di/Muwa
7120  Fe1=0
7123  Fe2=0
7126  Cf=1.
7127  Prwf=Prw
7128  Reif=Re
7129  Ift=0
7131  Two=Tsat-5
7132  Tfilm=Tsat/3+Two*2/3
7135  Kf=FNKw(Tfilm)
7138  Rhof=FNRhow(Tfilm)
7141  Muf=FNMuw(Tfilm)
7144  Hfgp=FNHfg(Tsat)+.68*FNCpw(Tfilm)*(Tsat-Two)
7147! New=Kf*(Rhof^2*9.81*Hfgp/(Muf*Do*Qp))^.3333
7148  New=(Kf^3*9.81*Hfgp*Rhof^2/(Muf*Do*(Tsat-Two)))^.25
7150  IF Ioc=1 THEN
7153! New=Kf*((9.81*Hfgp/Qp)^.25)*((Muf*Do)^(-.375))*(Rhof^.625)*(Vv^.125)
7154  New=(9.81*Hfgp/(Tsat-Two))^.2*Kf^.8*Vv^.1*Rhof^.5/(Do*Muf)^.3
7156  END IF
7159  Ho=Alp*New
7162  Twoc=Tsat-Qp/Ho
```

```
165  IF ABS((Twoc-Two)/Twoc)>.001 THEN
168  Two=Twoc
171  GOTO 7132
174  END IF
175  Rexpi=Rexp
184  IF Ihi=0 THEN
186  Omega=Re^Rexpi*Prw^.3333*Cf
187  END IF
188  IF Ihi=1 THEN
189  Sra=.88-(.24/(4.+Prwf))
190  Srb=.333333+.5*EXP(-6*Prwf)
191  Omega=(5.+.015*Reif^Sra*Prwf^Srb)
192  END IF
193  IF Ihi=2 THEN
194  Epsi=(1.82*LGT(Re)-1.64)^(-2)
195  Ppk1=1.+3.4*Epsi
196  Ppk2=11.7+1.8*Prw^(-1/3)
197  Pp1=(Epsi/8)*Re*Prw
198  Pp2=(Ppk1+Ppk2*(Epsi/8)^.5*(Prw^.6666-1))
199  Omega=Pp1/Pp2
200  END IF
'202  Hi=Kw/Di*Ci*Omega
'203  IF Ife=0 THEN 7216
'204  P1=PI*(Di+D1)
'205  P2=PI*(Di+D2)
'206  A1=(D1-Di)*PI*(Di+D1)*.5
'207  A2=(D2-Di)*PI*(Di+D2)*.5
7208  M1=(Hi*P1/(Kcu*A1))^.5
7209  M2=(Hi*P2/(Kcu*A2))^.5
7210  Fe1=FNTanh(M1*L1)/(M1*L1)
7213  Fe2=FNTanh(M2*L2)/(M2*L2)
7216  Dt=Q/(PI*Di*(L+L1*Fe1+L2*Fe2)*Hi)
7217  IF Ihi=0 THEN
7219  Muwi=FNMuw(Tavg+Dt)
7222  Cfc=(Muwa/Muwi)^.14
7225  IF ABS((Cfc-Cf)/Cfc)>.001 THEN
7228  Cf=(Cf+Cfc)*.5
7231  GOTO 7184
7232  END IF
7234  END IF
7235  IF Ihi=1 THEN
7236  Prwfc=FNPrw(Tavg+Dt)
7237  Reifc=Vw*Di*FNRhow(Tavg+Dt)/FNMuw(Tavg+Dt)
7239  IF ABS((Prwfc-Prwf)/Prwfc)>.001 OR ABS((Reifc-Reif)/Reifc)>.001 THEN
7240  Prwf=(Prwfc+Prwf)/2.
7241  Reif=(Reifc+Reif)/2.
```

```
7242  GOTO 7184
7243  END IF
7245  END IF
7246  Ift=Ifto
7247  X=Do*New*L/(Omega*Kw*(L+L1*Fe1+L2*Fe2))
7248  Y=New*(1/Uo-Rm)
7249! COMPUTE COEFFICIENTS FOR THE LEAST-SQUARES-FIT STRAIGHT LINE
7250  IF Jp=1 THEN OUTPUT @Io_path;X,Y
7252  Sx=Sx+X
7255  Sy=Sy+Y
7258  Sxs=Sxs+X*X
7261  Sxy=Sxy+X*Y
7264  IF Im=1 AND Jj=0 THEN OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Em
*)
7267  J=J+1
7270  IF J<Nrun THEN 6925
7273  S1=(Nrun*Sxy-Sy*Sx)/(Nrun*Sxs-Sx^2)
7276  IF Iwi1=2 THEN
7279!    IF Inn=1 AND Di=.009525 THEN S1=1/.051   !TO BE MODIFIED
7282!    IF Inn=0 THEN S1=1/.012
7283!    IF Inn=3 THEN S1=1/.22
7285!    IF Inn=1 AND Di=.0127 THEN S1=1/.052
7286!    IF Ift=2 THEN S1=1/.035
7287  IF Ihi=0 THEN S1=1/.027
7288  IF Ihi=1 THEN S1=1/1.00
7289  IF Ihi=2 THEN S1=1/1.00
7291  END IF
7294  Ac=(Sy-S1*Sx)/Nrun
7297  Cic=1/S1
7300  Alpc=1/Ac
7303  Jj=Jj+1
7306  IF Jp=1 THEN Jp=2
7309  Cerr=ABS((Cic-Ci)/Cic)
7312  Aerr=ABS((Alpc-Alp)/Alpc)
7315  IF Cerr>.001 OR Aerr>.001 THEN
7318  Ci=(Cic+Ci)*.5
7321  Alp=(Alpc+Alp)*.5
7324  BEEP
7327  IF Ijob=1 THEN 6907
7330  ELSE
7333  IF Jp=0 THEN Jp=1
7336  END IF
7339  IF Jp=1 THEN 6874
7342  Ci=(Ci+Cic)*.5
7345  PRINT
7346  IF Ihi=0 THEN
```

```
348  PRINT USING "10X,""Ci (based on Sieder-Tate)         =  "",Z.4D";Ci
349  END IF
350  IF Ihi=1 THEN
351  PRINT USING "10X,""Ci (based on Sleicher-Rouse)      =  "",Z.4D";Ci
352  PRINT USING "10X,""Re exponent for Sleicher-Rouse  =  "",D.DDD";Sra
353  END IF
354  IF Ihi=2 THEN
355  PRINT USING "10X,""Ci (based on Petulhov-Popov)      =  "",Z.4D";Ci
356  END IF
357  IF Ioc=0 THEN
358  PRINT USING "10X,""Alpha (based on Nusselt (Tdel)) =  "",Z.4D";Alp
359  END IF
360  IF Ioc=1 THEN
361  PRINT USING "10X,""Alpha (based on Fujii (Tdel))    =  "",Z.4D";Alp
362  END IF
363  IF Inam=5 THEN
364  IF Ihi=0 THEN
366  IF Ipco=0 AND Inn=0 THEN Alpsm=.8218  !NO INSERT,VACUUM,S-T
367  IF Ipco=1 AND Inn=0 THEN Alpsm=.7793  !NO INSERT,ATMOSPHERIC,S-T
368  IF Ipco=0 AND Inn=3 THEN Alpsm=.7854  !HEATEX,VACUUM,S-T
369  IF Ipco=1 AND Inn=3 THEN Alpsm=.7769  !HEATEX,ATMOSPHERIC,S-T
371  END IF
372  IF Ihi=1 THEN
373  IF Ipco=0 AND Inn=0 THEN Alpsm=.8613  !NO INSERT,VACUUM,S-R
374  IF Ipco=1 AND Inn=0 THEN Alpsm=.8218  !NO INSERT,ATMOSPHERIC,S-R
375  IF Ipco=0 AND Inn=3 THEN Alpsm=.7791  !HEATEX,VACUUM,S-R
376  IF Ipco=1 AND Inn=3 THEN Alpsm=.7929  !HEATEX,ATMOSPHERIC,S-R
378  END IF
379  IF Ihi=2 THEN
380  IF Ipco=0 AND Inn=0 THEN Alpsm=.8205  !NO INSERT,VACUUM,P-P
381  IF Ipco=1 AND Inn=0 THEN Alpsm=.7654  !NO INSERT,ATMOSPHERIC,P-P
382  IF Ipco=0 AND Inn=3 THEN Alpsm=.7670  !HEATEX,VACUUM,P-P
383  IF Ipco=1 AND Inn=3 THEN Alpsm=.7708  !HEATEX,ATMOSPHERIC,P-P
385  END IF
386  END IF
387  IF Inam=4 THEN
390  IF Ipco=1 THEN Alpsm=.876  !SWENSEN DATA BASED ON DEL-T
391  END IF
392  IF Inam=0 OR Inam=3 THEN
393  IF Ipco=0 THEN Alpsm=.83   !VP M1STV103
394  IF Ipco=1 THEN Alpsm=.88   !VP SMTHSTA65
396  IF Ift=1 THEN Alpsm=.733   !ZEBROWSKI (V = 0.45 m/s)
397  IF Ift=1 THEN Alpsm=.677   !VAN PETTEN (V = 0.25 m/s)
398  IF Ift=2 THEN Alpsm=1.262
399  END IF
401  IF Inam=1 THEN  !MITROU ALPHA FOR P-P FROM REPROCESSING
```

```
7402  IF Ipco=0 THEN Alpsm=.8437
7403  IF Ipco=1 THEN Alpsm=.8418
7404  END IF
7405  Et=Alp/Alpsm
7406  Eq=Et^1.333333
7407  PRINT USING "10X,""Enhancement (q)                        = "",DD.3D";Eq
7408  PRINT USING "10X,""Enhancement (Del-T)                    = "",DD.3D";Et
7409  ASSIGN @File TO *
7410  SUBEND
7519  SUB Modify
7520  COM /Fld/ Ift,Istu
7522  DIM Emf(20)
7525  BEEP
7528  INPUT "ENTER NAME OF FILE TO BE MODIFIED",Fileo$
7531  ASSIGN @Fileo TO Fileo$
7534  CREATE BDAT "TEST",30
7537  ASSIGN @Filed TO "TEST"
7540  ENTER @Fileo;Ifg,Inn
7543  OUTPUT @Filed;Ifg,Inn
7544  IF Istu=0 THEN
7546  ENTER @Fileo;Iwt,Fp,Fw,Fh
7547  OUTPUT @Filed;Iwt,Fp,Fw,Fh
7548  ELSE
7549  IF Ifg=0 THEN
7551  ENTER @Fileo;Iwt
7552  OUTPUT @Filed;Iwt
7553  END IF
7554  IF Ifg=1 THEN
7555  ENTER @Fileo;Fp,Fw,Fh
7556  OUTPUT @Filed;Fp,Fw,Fh
7557  END IF
7559  END IF
7560  BEEP
7561  INPUT "ENTER NUMBER OF DATA SETS STORED",N
7562  FOR I=1 TO N
7563  IF Istu=0 THEN
7565  ENTER @Fileo;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
7566  ELSE
7567  ENTER @Fileo;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T
T2,Phg,Pwater
7568  END IF
7570!   PERFORM CORRECTIONS
7571  PRINT USING "2X,""DO YOU WISH TO DELETE POINT"",DD,""?""";I
7572  INPUT "0=YES, 1=NO",Idel
7573  IF Idel=0 THEN 7580
7576  IF Istu=0 THEN
```

```
577  OUTPUT @Filed;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
578  ELSE
579  OUTPUT @Filed;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1
T2,Phg,Pwater
580  END IF
581  NEXT I
582  ASSIGN @Fileo TO *
583  ASSIGN @Filed TO *
584  SUBEND
585  SUB Purg
588  BEEP
591  INPUT "ENTER FILE NAME TO BE DELETED",File$
594  PURGE File$
597  GOTO 7588
600  SUBEND
690  SUB Renam
693  BEEP
696  INPUT "ENTER FILE NAME TO BE RENAMED",File1$
699  BEEP
702  INPUT "ENTER NEW NAME FOR FILE",File2$
705  RENAME File1$ TO File2$
708  GOTO 7693
711  SUBEND
721  DEF FNTvsv55(V)
731  COM /Cc55/ T55(5)
741  T=T55(0)
751  FOR I=1 TO 5
761  T=T+T55(I)*V^I
771  NEXT I
781  RETURN T
791  FNEND
801  DEF FNTvsv56(V)
811  COM /Cc56/ T56(5)
821  T=T56(0)
831  FOR I=1 TO 5
841  T=T+T56(I)*V^I
851  NEXT I
861  RETURN T
871  FNEND
881  DEF FNTvsv57(V)
891  COM /Cc57/ T57(5)
901  T=T57(0)
911  FOR I=1 TO 5
921  T=T+T57(I)*V^I
931  NEXT I
941  RETURN T
951  FNEND
961  DEF FNTvsv58(V)
971  COM /Cc58/ T58(5)
981  T=T58(0)
991  FOR I=1 TO 5
```

```
8001  T=T+T58(I)*V^I
8011  NEXT I
8021  RETURN T
8031  FNEND
```

## LIST OF REFERENCES

1. Harrington, R. L., *Marine Engineering*, Society of Naval Architects and Marine Engineers, New York, New York. pp 465-473, 1971.

2. Marto, P.J., *Heat Transfer in Condensation*, Boilers, Evaporators, and Condensers, ed. by S. Kakal, John Wiley and Sons, pp. 525-570, 1991.

3. Boyd, L.W., Hammon, J.C., Littrell, J., and Withers, J.G., *Efficiency Improvement at Gallatin Unit 1 with Corrugated Condenser Tubing*, ASME 83-JPGC-PWR-4, Presented at Joint Power Generation Conference, 1983.

4. Van Petten, T.L., *Filmwise Condensation on Low Integral-Fin Tubes of Different Diameters*, Master's Thesis, Naval Postgraduate School, Monterey, California, December 1988.

5. Swensen, K.A., *Further Studies in Filmwise Condensation of Steam on Horizontal Finned Tubes*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1992.

6. Sieder, E.N., and Tate, C.E., *Heat Transfer and Pressure Drop of Liquids in Tubes*, Industrial Engineering Chemistry, vol. 28, pp. 1429, 1936.

7. Kanakis, G.D., *The Effect of Condensate Inundation Steam Condensation Heat Transfer to Wire-Wrapped Tubing*, Master's Thesis, Naval Postgraduate School, Monterey, California, June 1983.

8. Brower, S.K., *The Effect of Condensate Inundation on Steam Condensation Heat Transfer in a Tube Bundle*, Master's Thesis, Naval Postgraduate School, Monterey, California, June 1985.

9. Mitrou, E.S., *Film Condensation of Steam on Externally Enhanced Horizontal Tubes*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1986.

10. Nusselt, W., "Die Oberflachen-Kondensation des Wasserfampfes," VDI Zeitung, vol. 60, pp. 541-546, 569-575, 1916.

11. Shekriladze, I.G. and Gomelauri, V.I., *Theoretical Study of Laminar Film Condensation of Flowing Vapour*, International Journal of Heat and Mass Transfer, vol. 9, pp. 581-591, 1966.

12. Fujii, T., Honda, H., and Oda, K., *Condensation of Steam on a Horizontal Tube -- the Influences of Oncoming Velocity and Thermal Condition at the Tube Wall*, Condensation Heat Transfer, The 18th National Heat Transfer Conference, San Diego, California, pp. 35-43, August 1979.

13. Rose, J.W., *Fundamentals of Condensation Heat Transfer: Laminar Film Condensation*, JSME International Journal, Series II, vol. 31, no. 3, pp. 357-375, 1988.

14. Thomas, D.G., *Enhancement of Film Condensation Heat Transfer Rates on Vertical Tubes by Vertical Wires*, Ind. Eng. Chem., Fund., Vol. 6, pp. 97-102, 1967.

15. Sethumadhavan, R., and Rao, R., *Condensation of Steam on a Single Start and Multistart Spiral Wire-Wound Horizontal Tubes*, Ind. Eng. Chem. Process Des. Dev., vol. 24, pp. 783-787, 1985.

16. Fujii, T., Wang, W., Koyama, S., and Shimizu, Y., *Heat-Transfer Enhancement for Gravity Controlled Condensation on a Horizontal Tube by Coiled Wires*, Beijing Conference, 1985.

17. Marto, P.J., Wanniarachchi, A.S., Mitrou, E., *Film Condensation of Steam on a Horizontal Wire-Wrapped Tube*, 2nd ASME-JSME Thermal Engineering Joint Conference, Honolulu, Hawaii, March 1987.

18. Marto, P.J., and Wanniarachchi, A.S., *The Use of Wire-Wrapped Tubing to Enhance Steam Condensation in Tube Bundles*, Heat Transfer in Heat Rejection Systems, ASME, pp. 9-16, 1984.

19. Withers, J.G., and Young, E.H., *Steam Condensing on Vertical Rows of Horizontal Corrugated and Plain Tubes*, I&CE Process Design and Development, vol. 10, pp. 19-30, January 1971.

20. Catchpole, J., and Drew, B., *Steam Turbine Condensers*, NEL Report No. 619, pp. 68-80, September 1974.

21. Mehta, M.H., and Rao, M.R., *Heat Transfer and Frictional Characteristics of Spirally Enhanced Tubes For Horizontal Condensers*, Advances in Advanced Heat Transfer, ASME, New York, pp. 11-21, 1979.

22. Marto, P.J., Reilly, D.J., and Fenner, J.H., *An Experimental Comparison of Enhanced Heat Transfer Condenser Tubing*, Advances in Advanced Heat Transfer, ASME, New York, pp 1-9, 1979.

23. Cunningham, J., and Bahjernejad, M., *The effect of Vapour Shear and Condensate Drainage in Condenser Roped Tubes*, Desalination, vol. 45, pp. 135-142, 1983.

24. Cunningham, J., Boudinar, M.B., *The Effect of Condensate Inundation on the Performance of Roped Tubes*, Condensers and Condensation Proc. 2nd International Symposium, March 1990.

25. Mussalli, Y.G., and Gordon, L.S., *Use of Enhanced Heat Transfer Tubes in Power Plant Condensers*, HTD, Heat Transfer in Heat Rejection Systems, vol. 37, pp. 27-32, 1984.

26. Poole, W.M., *Filmwise Condensation of Steam on Externally-Finned Horizontal Tubes*, Master's Thesis, Naval Postgraduate School, Monterey, California, December 1983.

27. Marto, P.J., *Recent Progress in Enhancing Film Condensation Heat Transfer on Horizontal Tubes*, Heat Trans. Engrg., vol. 7, pp. 61-71, 1986.

28. Sleicher, C.A. and Rouse, M.W., *A Convenient Correlation for Heat Transfer to Constant and Variable Property Fluids in Turbulent Pipe Flow*, International Journal of Heat and Mass Transfer, vol. 18, pp. 677, 1975.

29. Petukhov, B.S., *Heat Transfer and Friction in Turbulent Pipe Flow with Variable Fluid Properties*, Advances in Heat Transfer, vol. 6, pp. 503, 1970.

30. Lorenz, J.J., Yung, D., Panchal, C., and Layton, G., *An Assessment of Heat Transfer Correlations for Turbulent Flow of Water at Prandtl Numbers of 6.0 to 11.6*, Argonne National Laboratory, Argonne, Illinois, January 1981.

31. Guttendorf, M.B., *Further Developments in Filmwise Condensation of Steam on Horizontal Integral Finned Tubes*, Master's Thesis, Naval Postgraduate School, Monterey, California, June 1990.

32. Micheal, A.G., Marto, P.J., Wanniarachchi, A.S., and Rose, J.W., *Effect of Vapor Velocity During Condensation on Horizontal Smooth and Finned Tubes*, HTD, Heat Transfer with Phase Change, vol. 114, pp. 1-10, 1989.

33. Kline, S.J., and McClintock, F.A., Describing Uncertainties in Single-Sample Experiments, Mechanical Engineering, vol. 74, pp. 3-8, January 1953.

34. Georgiadis, I.V., *Filmwise Condensation of Steam on Low Integral-Finned Tubes*, Master's Thesis, Naval Postgraduate School, Monterey, California, September 1984.

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